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February 27, 1987

Mr. Rodger Field
United States Environmental
Protection Agency
230 South Dearborn
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Dear Rodger:

Enclosed are two copies of the risk assessment done by Dr. Crump and colleagues on the OMC NPL site. This document has been prepared in an effort to resolve the dispute between the government and Outboard Marine Corporation (OMC). This risk assessment compares the risk due to the remedy selected by the Record of Decision to an in-place containment (IPC) remedy.

It is important to note that the IPC evaluated in the risk assessment was based on a proposal previously developed by consultants to the government; it differs from the IPC approach discussed with EPA officials on December 1, 1986. OMC and its consultants believe that the IPC design as discussed on December 1, is at least as protective of human health and the environment as the IPC design evaluated by this risk assessment. Therefore, while the design details differ, OMC believes that the relative risk posed by the IPC approach is much less than posed by the ROD alternative, as demonstrated by the enclosed summary.

In the course of the development of this document, every effort has been made to follow U.S.EPA guidelines for preparation of a quantitative risk assessment. It is our understanding that all scientists do not agree or accept the highly conservative assumptions and concepts used by EPA and followed here. In particular, OMC does not believe that the risk assessment procedure, because of its highly conservative nature, predicts real risk. Nevertheless, we believe that EPA's risk assessment procedures confirm our view that the suggested IPC design is a preferred cost-effective remedy to the remedy selected by the ROD.

We look forward to your response.

Very truly yours,

JEFFREY C. FORT

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1. Introduction

1.1. Background

The Outboard Marine Corporation (OMC) operates facilities located on an industrial and commercial site adjacent to Lake Michigan in Waukegan, Illinois, approximately 37 miles north of Chicago. The site is near Waukegan Harbor, an irregularly shaped arm of Lake Michigan having a surface area of approximately 42 acres (Figure 1-1). Other industrial facilities located in the area include Larsen Marine, a National Gypsum plant, Falcon Marine, and the Waukegan Water Filtration plant. A public beach is located on the eastern edge of the OMC property. Public launching ramps, mooring sites, slips, and other facilities for small boats are also located in the harbor, primarily in the southern portion. Various fish species are found in the Waukegan area of Lake Michigan, many of which are valuable to sport and commercial fishing industries.

It appears that, beginning in the late 1950's, OMC utilized hydraulic fluids containing polychlorinated biphenyls (PCBs)[1] in its

[1]Polychlorinated biphenyls are comprised of mixtures of biphenyl compounds with varying amounts of chlorine. Commercial PCBs, due to their resistance to breakdown from fire and heat and their electrical insulating capacity, had been widely used in numerous industrial applications since their introduction in the 1920s. PCBs were identified as a potentially hazardous environmental contaminant during the 1960s. In 1971 the principal manufacturer of PCBs voluntarily ceased PCB production for all "open-ended" applications (applications where emissions into the environment cannot be controlled), and completely discontinued production in 1977 (IARC, 1978 and Monsanto Company, 1979 In: James *et al.*, 1981).

die-casting facility, OMC plant #2, located just north of Slip #3 (Figure 1-1). In 1971, OMC ceased purchasing PCB-containing hydraulic fluids.

In 1976, the U. S. Environmental Protection Agency (EPA) notified OMC that it had found high concentrations of PCBs in the sediment and water of Waukegan Harbor as well as in the soil in the vicinity of the OMC plant. Since the discovery of PCBs on the OMC site, many studies have been undertaken to determine PCB concentration and export of PCBs from the site, and the potential impact of PCBs originating from this site on the environment. These investigations have revealed three major areas with elevated PCB concentrations: Waukegan Harbor, particularly-Slip #3; the surface runoff drainage area called the North Ditch, which includes the Crescent Ditch and Oval Lagoon; and a parking lot north of the OMC plant (Figure 1-1).

1.2. Purpose of This Study

Utilizing the information gathered from this site, results of transport modelling for the site, and knowledge of environmental properties of PCBs, the EPA has determined that remedial actions in the Waukegan Harbor, the North Ditch area and parking lot area of the OMC property are needed. Several remedial action plans have been proposed, of which two will be evaluated in this document. These include a plan proposed by the EPA and an alternative plan. The purpose of this report is to provide a comparative assessment of the risk to human health from exposure to PCBs from the OMC site, that can then be used to assess benefits and costs of two of these remedial alternatives.

1.3. Description of Remedial Alternatives

The remedial action plan selected by the EPA was described in its Record of Decision (USEPA, 1984). The proposed plan, herein referred to as the ROD alternative, is a fund-balanced approach that the EPA expects to be effective in preventing migration of PCBs from the site. The other remedial alternative being evaluated is referred to as the in-place containment alternative (IPC). These are briefly described below and details are provided in Chapter 4.

Record of Decision Alternative (ROD): Under the ROD alternative, all sediments in Waukegan Harbor and the North Ditch area containing greater than 50 ppm PCBs will be removed and confined to prevent migration of PCBs into the environment. The sediments containing the highest concentrations of PCBs (those containing greater than 10,000 ppm PCBs) will be removed and disposed of offsite in a licensed hazardous waste facility. Sediments with lower PCB concentrations will be dredged, dewatered in clay-lined lagoons to be constructed on vacant OMC property, and ultimately confined in containment cells to be constructed on the OMC parking lot or in the Crescent Ditch/Oval Lagoon areas.

In-Place Containment Alternative (IPC): An alternative plan, the In-Place Containment (IPC), proposes to confine, on site, all sediments in Waukegan Harbor containing more than 50 ppm PCB. Under this alternative, a containment cell will be built by constructing a slurry wall between Slip #3 and the upper harbor. The upper harbor will be dredged to remove sediments containing greater than 50 ppm PCBs and the dredged material will be deposited behind the slurry wall. The slip will then be capped with clay to prevent PCB migration. It is also proposed that a storm drain be constructed through the parking lot to divert surface runoff and process water away from the North Ditch area and into Lake Michigan. The entire North Ditch area will then be filled, temporarily dewatered so that the sediment can be capped with clay, and covered with top soil and vegetation. Under the IPC plan analyzed here[2], no slurry wall would be constructed around the Crescent Ditch, Oval Lagoon, or the parking lot unless and until the migration of PCBs is detected. Monitoring wells will be constructed in the vicinity to detect any migration of PCBs through the groundwater and to assess the need for further remedial action to minimize this transport.

1.4. Evaluation of Potential Health Risks

The evidence that PCBs have the potential for causing some health effects is derived principally from animal studies. As with any substance, the potential for adverse health effects is determined by both the degree of exposure and the potency of the substance for causing the effects. Therefore, risk depends not only on the potency or intrinsic toxicity of PCBs (that is, the amount of PCBs required to produce harm), but also the amount of PCBs to which humans are exposed.

[2]This analysis does not include provisions for analyzing the risk once slurry walls are constructed around Slip #3, the North Ditch area (to include the Crescent Ditch and Oval Lagoon), and the parking lot. Installation of slurry walls more accurately represents OMC's current proposal to EPA, and it is believed that the installation of slurry walls will be more protective than the scenario analyzed herein.

Evaluation of the potential for health risks is a three step process consisting of exposure assessment, hazard assessment, and risk characterization. Exposure assessment is the estimation of the amount of PCBs to which humans are expected to be exposed in both of the remedial alternatives studied. Hazard assessment is the qualitative evaluation of experimental data to determine the potential of developing adverse health effects as a result of exposure to PCBs. Risk characterization is the estimation, based upon the data evaluated in the hazard assessment step, of any increased risks to human health from the exposures estimated in the exposure assessment. Accordingly, in this assessment both the potency of PCBs for causing various health effects and the expected exposures to humans as a result of implementing each of the remedial alternatives are evaluated.

There is considerable uncertainty as to both the extent of exposure and the effects upon human health as a result of this exposure to PCBs from the Waukegan Harbor area. Actual measurements of environmental releases and human exposures are not available for all exposure routes even under present conditions, and clearly are not available for the remedial action scenarios being evaluated. Therefore, exposures are estimated using mathematical models that require informed judgments regarding the specific remedial actions and environmental conditions. Additional uncertainty results from quantifying the potential for human health effects using experimental animal data. Mathematical dose response models are used to estimate the effect of environmental exposures upon humans using data on animals exposed to much larger doses of PCBs. Such application of mathematical models is frequently made in the regulatory communities. In this risk assessment, these exposure and dose response models are an integral part of the evaluation of expected site responses under competing management alternatives.

Elements of uncertainty that are inherent in these analyses are addressed by providing two types of estimates: "more probable" and "worst case." "More probable" estimates of exposure involve use of reasonable, best estimate values for parameters derived from theory, data, and model results. These estimates are intended to represent best professional judgment regarding potential exposures. To obtain "more probable" estimates of risk these estimated exposures are applied to conservative (health protective) estimates of the potency of PCBs for causing health effects. Hence, even the "more probable" risk estimates involve use of health protective assumptions. "Worst case" estimates are intended to provide plausible upper bounds to PCB exposures and resulting potential risks to humans. These estimates are based upon data from among the higher postulated exposure levels rather than more likely levels; similar conservative approaches are used in estimating dermal uptake rates, bioaccumulation factors, and other biological, chemical and physical constants. In addition, care is taken to make the analyses of the different alternative actions comparable by using identical or similar approaches and assumptions in evaluating each remedial alternative, insofar as is appropriate. As a result, there should be less uncertainty in estimates of relative levels of risk between two alternative remedial actions than in estimates of absolute levels of risk. Details of the assumptions and approaches used in estimating human exposure and risk are fully discussed and documented in the text of this document.

1.4.1. Exposure Assessment

Estimation of human exposure due to the presence of PCBs in Waukegan Harbor and its vicinity is an involved process. It requires assumptions regarding the specific procedures to be followed in the remedial actions; it requires simulation and forecasting of the levels of contamination in the different environmental compartments (air, the water column, the underlying sediment, and fish) for the remedial alternatives under consideration; and it requires judgments about human behavior regarding such activities as fishing, fish consumption, boating activities, swimming, etc. Details of the approaches used in estimating exposures are provided in subsequent chapters.

1.4.1.1. Environmental Modelling

Assessment of risk to human health and to the environment due to the PCBs in Waukegan Harbor and its vicinity requires simulation and forecasting of the levels of PCBs in the different environmental compartments. Some of the possible routes of human exposure to PCBs are dermal contact, inhalation, drinking water, and ingestion of fish. PCBs are known to accumulate in fish with the result that the concentration of PCBs in fish exceeds that in the ambient water. In order to examine the response of PCB levels in water and fish to the two proposed remedial actions, a mathematical model was developed, calibrated and applied to assess the fate (movement and longevity) of PCBs in the Waukegan Harbor region.

The environmental model is used to estimate the distribution of PCBs in the study area during and after the proposed cleanup activities. The framework and parameters of the model utilized in these analyses are very similar to those of previous modelling efforts funded by the EPA. These efforts are reviewed in Chapter 5. From this base, the model applications are expanded to include potential ramifications of the two proposed remedial actions. From these projections potential PCB loads to the environment are estimated for each alternative.

The results of the investigations are divided into two categories. These are steady-state, "long-term responses"; and "short-term" impacts. Of primary concern is the impact of actions associated with the process of dredging and excavation that are proposed in the ROD or IPC remedial alternatives. The projections of the average PCB distribution obtained by the model simulations were utilized to estimate PCB levels in air, in the water column, and in resident fish in the lake for both of the remedial alternatives.

1.4.1.2. Estimates of Human Exposure

According to the EPA Record of Decision, humans are potentially exposed to PCBs from the OMC site by several routes including: ingestion of fish, inhalation of volatilized PCBs, drinking water, and a variety of recreational activities including boat washing and swimming. Each of these potential routes of exposure is briefly described in the following paragraphs. The potential extent of exposure and the resulting risks are evaluated for each of these exposure pathways.

Exposure through inhalation: PCBs originating from the OMC site may enter the air by evaporating from water in the harbor and North Ditch areas. Even though PCBs are relatively nonvolatile, the amounts of PCBs at the site make air a source of potential exposure to the population in the area. Using local meteorological data and output from the model for volatilization loads from the harbor and North Ditch area, the movement of airborne PCBs from the site is estimated through application of atmospheric dispersion models.

Exposure through ingestion of fish: The potential of exposure to PCBs from the OMC site through ingestion of fish is particularly important because fish are known to bioaccumulate PCBs and the waters of Lake Michigan near Waukegan are heavily fished. Estimates of PCB levels in fish caught in and adjacent to Waukegan Harbor are used to estimate exposure to those who consume these fish.

Exposure through dermal contact: Concern is expressed in the EPA Record of Decision that persons might be exposed dermally to PCB-containing sediments from the harbor. To evaluate the possible extent of such exposure a scenario is evaluated in which persons are assumed to be exposed through washing PCB-containing mud and silt from boats.

Exposure through drinking water: The City of Waukegan maintains an emergency drinking water intake in Waukegan Harbor. Although this intake is seldom used, it nevertheless is an integral part of the water

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Risk Assessment on Polychlorinated Biphenyls for Outboard Marine Corporation Site

Final Report

prepared by

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February 26, 1987

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supply system. Should the city need to utilize the emergency intake, PCBs from the harbor could be introduced into the drinking water system. Historical data on the frequency of use of the emergency water intake and estimates of PCB water concentration levels were utilized to calculate exposure to persons drinking water from this intake.

Exposure through swimming: Exposure to PCBs during swimming could occur through dermal uptake and through ingestion of PCB-containing water. Estimates of total lifetime exposures are based on the assumption that a person swims regularly near the public beach for 30 years.

1.4.2. Hazard Assessment

A thorough review of the PCB literature was conducted to identify the potential health effects that PCBs might cause and to determine the dose response relationships between exposure and effect. Included in this review was the literature on human exposure to PCBs and potential health effects from such exposure. Critical review of the available studies in humans indicated that, due to contamination of the PCBs with other compounds and poor exposure information, the data are unsuitable for quantitative risk assessment. Since definitive quantitative human data on PCB toxicity are not available, assessment of the potential hazards from PCB exposure is based upon animal bioassay data. Available mammalian toxicity data for PCB mixtures and for specific PCB compounds were qualitatively described, critically reviewed, and summarized in a separate document. Types of health effects considered include carcinogenic effects (cancer) and noncarcinogenic effects such as teratogenic effects (birth defects or malformations), fetotoxic effects (alterations in growth and development of the fetus), other reproductive effects (infertility or miscarriage), immunological effects, and a variety of effects collectively referred to as systemic effects, which include damage to the liver, the gastrointestinal tract, and the central nervous system.

For each type of adverse effect (systemic, reproductive, teratogenic, fetotoxic, or carcinogenic) the study that demonstrates, toxicologically and statistically, the greatest toxic potential from exposure to any PCB has been selected for making quantitative estimates of risk. In keeping with the "worst case" approach, results of experimental studies are interpreted conservatively; for example, whenever there are two plausible but conflicting interpretations of experimental results, the interpretation providing the highest potential risk to humans is generally used.

1.4.3. Risk Characterization

Risk characterization is the quantitative estimation, based upon the data evaluated in the hazard assessment step, of any increased risks to human health from the exposures estimated in the exposure assessment. The first phase of risk characterization is dose response assessment, which involves determining quantitatively the relationship between levels of exposure and the likelihood of resulting health effects.

In this document dose response curves for carcinogenic effects (cancer) are developed using the mathematical dose response model known as the multistage model, which is the model used in EPA risk assessment. Estimates based on this model are generally regarded as "reasonable upper bounds on risk" rather than precise estimates. For noncarcinogenic effects, "no observable effect levels" (NOELs) that are derived from animal toxicity studies are identified. The results of the dose response assessment are combined with those of the exposure assessment to arrive at quantitative determinations of the potential risks to human health from exposure to PCBs. For cancer these take the form of estimates of extra lifetime risk of cancer from exposure to PCBs, and for other health effects they are in the form of "margins of safety" that compare NOELs to estimated exposure levels. Further information on the approaches to hazard assessment and risk characterization used in this report are contained in Chapters 2 (2.1.) and 6 (6.1.).

Comparative risk estimates concerning the remedial alternatives analyzed in this document are discussed in Chapter 8 and indicate that the In-Place Containment alternative results in lower estimates of risk to human health than the Record of Decision alternative. Further qualification of this finding may be found in Chapter 8.

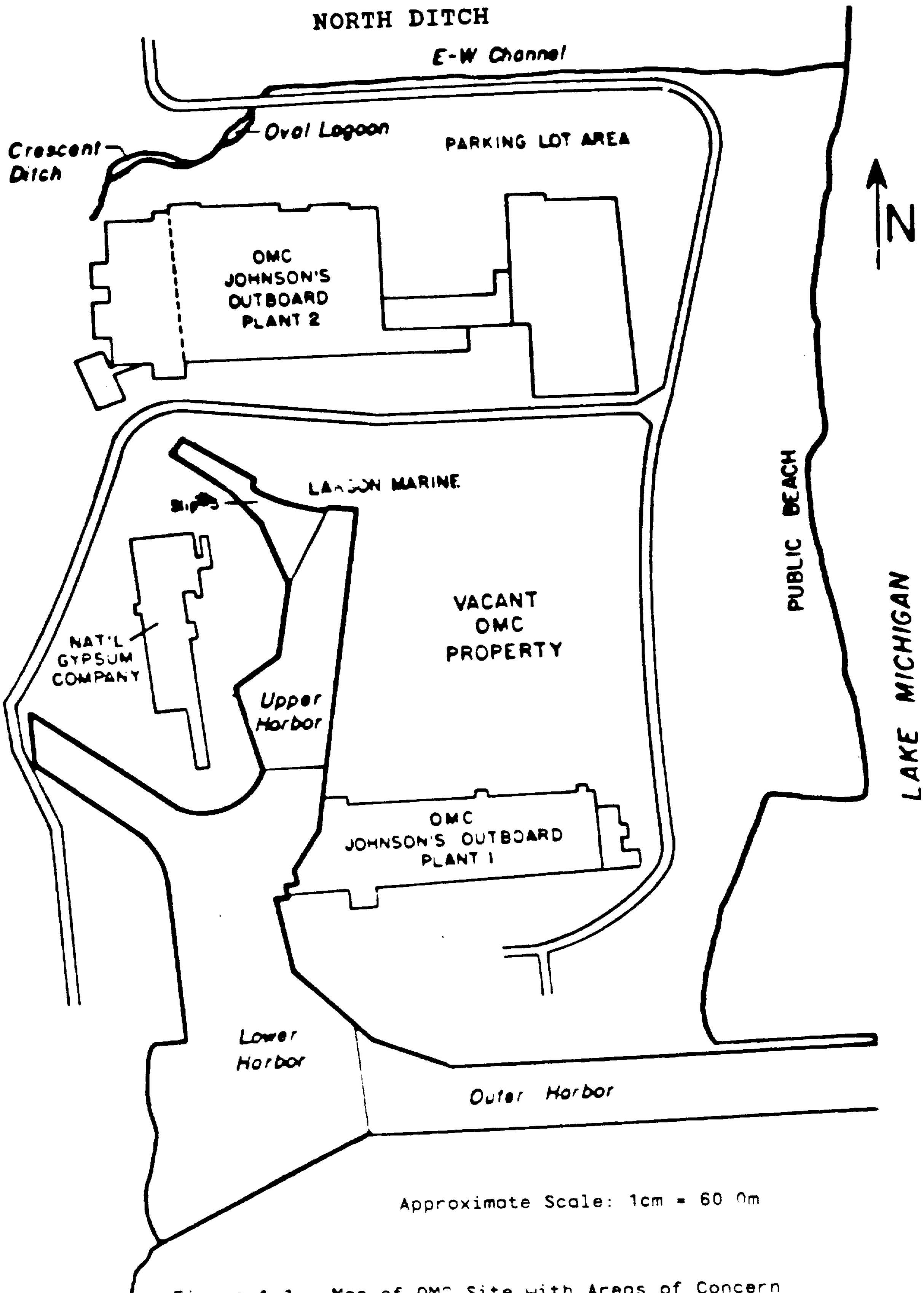


Figure 1-1. Map of OMC Site with Areas of Concern

2. Quantitative Assessment of Potency of PCBs for Causing Various Health Effects

2.1. Introduction

Toxicity is defined as any harmful effect caused by a chemical or a drug on a target organism. Virtually every known chemical has the potential to produce toxic effects if present in sufficient quantity, and there is a wide spectrum of doses needed to produce minimal harmful effects, serious injury or death. Whether or not a toxic effect occurs is dependent on the chemical and physical properties of the agent, the exposure situation, and the susceptibility of the biological system or subject. To fully characterize the potential toxicity of a chemical, information about the nature of the exposure, the susceptibility of the subject, the types of effects produced by the chemical, and the doses required to produce those effects should be considered.

The critical factors in practical situations depend not only on the intrinsic toxicity of a substance, that is, the amount of substance required to produce harm, but also the risk or hazard associated with the use patterns. Risk assessment takes into account possible harmful effects on individuals or on society from the use of material in the quantity and in the manner proposed.

In order to evaluate the risk from exposure to PCBs both the exposure conditions and the toxicity of PCBs must be assessed. Because definitive data in humans needed for risk assessment is not available for PCBs, animal bioassay data were used for hazard assessment in this document. Data on the toxicity of PCBs to animals in combination with estimates of human exposures are used to estimate the potential hazard to humans. Such use of animal data is commonly made by EPA to assess hazards to humans from exposure to chemical agents. Therefore, the main purpose of reviewing toxicity tests is to provide a data base that can be used to assess the risk associated with a defined exposure circumstance. The ideal case is one in which the agent, subject, and exposure conditions used for the toxicity tests are identical to those which will be encountered in the defined expcsure circumstance. In most cases there is a difference between the toxicity testing situation and the "real world" situation. Risk estimation therefore requires some extrapolation to predict the risk or hazard in exposure conditions not covered by the data base.

2.2. Potency Assessment Methods for Noncarcinogenic Effects

Estimates of risk for noncarcinogenic health hazards are evaluated by comparing the level of human exposure estimated from the environmental models or exposure scenarios with the "no observable effect levels" (NOELs) derived from animal toxicity studies to arrive at margins of safety (MOS) for systemic, reproductive, fetotoxic, teratogenic or immunologic effects. The MOS were calculated by dividing the NOEL in the most sensitive species (the highest NOEL in a single experiment that resulted in the smallest NOEL from among experiments on various species) by the maximum estimated daily human exposure.

In contrast, the allowable daily intake (ADI) for a compound is determined by dividing the NOEL established in animal toxicity tests by a "safety factor" or "uncertainty factor". Although the safety factor for calculating ADIs may vary from 10 to 100 to 1,000 or greater, a safety factor of 100 is typically applied. The ADI refers to a human dose, measured in specific units, that reflects the dose level at which no adverse effects are expected to occur should humans be chronically exposed at that dose. The MOS is not a measure of dose or "safe dose", but rather, it is a ratio that denotes the relationship between the maximum daily human exposure estimate and the NOEL derived from animal studies. The MOS indicates the number of times lower (or higher) the estimated human exposure is than the animal NOEL. This procedure has been used by others including the U. S. Department of the Interior (1986).

The MOS for noncarcinogenic effects is generally calculated using a NOEL established in chronic toxicity testing. The NOEL is an experimental dose level (generally in mg/kg/day) such that no significant changes in any parameter evaluated were detected either at this level or any lower dose level. The NOEL does not imply that no adverse effects occurred, but rather, within the limits of a specific study, no adverse effects that were statistically different from those occurring in control animals were observed. In the absence of chronic exposure tests, particularly for systemic effects, a NOEL from subchronic tests may be used. Zeilhuis and Van Der Kreek (1979) cite research by McNamara, Weil, and others in support of the use of subchronic (3-6 months) exposure tests for the determination of a NOEL. They state that many toxic effects, such as abnormal alterations in body weight, organ weight, liver and kidney pathology, blood chemistry, etc. are usually evident within three months or less of exposure. It should be noted that a statistically significant finding in a biological parameter does not necessarily indicate an irreversible or life-threatening adverse effect. In the absence of an experimentally derived NOEL, the lowest dose at which an effect occurred, the lowest effect level (LEL), may be used.

The available mammalian toxicity data for each of the PCB mixtures, such as Aroclor 1248 or 1254, and for PCB isomers, such as 3,4,3',4'-tetrachlorobiphenyl were evaluated. Data on noncarcinogenic effects were critically reviewed. For each type of adverse effect considered, whenever possible, a NOEL and LEL were determined for each of the studies reviewed for each type of PCB congener tested.

2.3. Potency Assessment Results for Noncarcinogenic Effects

For each type of PCB and for each type of adverse effect, either systemic, reproductive, fetotoxic, teratogenic, or carcinogenic, the animal study that demonstrated the greatest toxic potential from exposure to the polychlorinated biphenyl was identified. According to the worst case philosophy, results of experimental studies were interpreted conservatively; for example, whenever there were two plausible but conflicting interpretations of experimental results, the interpretation implying the highest risk to humans generally was used. For each noncarcinogenic effect, the lowest NOEL or LEL determined from any study using any PCB formulation was selected for calculation of the margins of safety. The studies selected and the NOEL used in the calculation of margins of safety are identified in Table 2-1. Margins of safety calculated for noncarcinogenic effects are presented in Chapter 8.

Depending on the actual data, a MOS of 100 or greater may indicate that the human dose is small (compared to the NOEL) and that the risk to humans is likely to be negligible. The larger the MOS (the smaller the estimated human exposure compared to the animal NOEL), the lower the potential risk to human health. As the MOS approaches one (as the estimated human exposure approaches the NOEL in animals), the likelihood of risk to humans increases. The actual value of the MOS that would denote a negligible risk to humans will vary with the quality of the experimental data from which the NOEL was derived. In most cases, a MOS of 100 or greater (the estimated human exposure is at least 100 times lower than the NOEL) would indicate that the risk to humans at the specified exposure would be minimal. The use of 100 as minimum value for the MOS is a conservative comparison for the following reasons: the "more probable" estimated human dose is based on data derived from median exposure values and conservative assumptions, while the "worst case" values are derived from data and assumptions that provide the highest estimates; the NOELs in animals are derived from the most sensitive species tested; and MOS compare generally brief (possible single-day) human exposures to average daily animal exposures over a lifetime chronic study or a 90-day subchronic study.

2.4. Potency Assessment Methods for Carcinogenesis

Historically, the NOEL-safety factor approach has been used to assess risk with respect to both carcinogenic and noncarcinogenic health effects. However, in recent years, estimating the risk of carcinogenic effects has increasingly involved the use of mathematical dose response models. This departure from the NOEL-safety factor approach has arisen primarily because for many carcinogens it is considered possible that any exposure, no matter how small, may involve some risk. This concept is thought particularly to be applicable to genotoxic carcinogens, that is, carcinogens for which either the parent compound or a metabolite interacts with DNA to initiate a cancer (Crump, 1985). It is now recognized that some chemicals may increase the incidence of cancer by means other than interacting with DNA. Very low levels of exposure to such "epigenetic" carcinogens are possibly without risk, although absolute identification of a carcinogen as either "genotoxic" or "epigenetic" is not currently possible. Therefore, in the current analysis, any level of exposure to a potential carcinogen will be considered to pose some risk.

Consequently, in the present analysis estimates of cancer risk have been obtained by fitting mathematical dose response models to cancer bioassay data. The fitted models are then used to predict risks at doses that humans might receive, which are typically much smaller than the doses applied in the animal bioassays.

The multistage dose response model (Crump *et al.*, 1977; Crump, 1984) is used in the present study. This model is widely used by Federal agencies [e.g., the Environmental Protection Agency (USEPA, 1980), the Occupational Safety and Health Administration (OSHA, 1983), and the Center for Disease Control (Kimbrough *et al.*, 1984)] and other state and private groups to assess risk from low exposures to carcinogens. The multistage model embodies the assumption that no level of exposure is completely safe and consequently even a single molecule theoretically could cause cancer.

The multistage model of cancer was originally developed by Armitage and Doll (1961). It is based upon the concept that cancer originates in a single cell and that several stages may be involved in the development of a cancer. Exposure to a carcinogen increases the rate at which a cell goes through one or more of these stages.

The mathematical form of the multistage model is

$$P(d) = 1 - \exp(-q_0-q_1d-\ldots-q_kd^k)$$

where d is the average lifetime daily dose of the chemical in mg/kg/day, P(d) is the probability of cancer from the dose level d, and $q_0,\ldots,q_k$ are nonnegative parameters estimated by fitting the model to experimental animal carcinogenicity data. The calculations involved in using this model must be carried out by computer. An updated version of the program GLOBAL82 (Howe and Crump, 1982) was used for this purpose in the present study.

The quantity of principal interest is not the absolute probability of a cancer P(d), but rather the extra lifetime risk of cancer resulting from exposure to a dose d. This risk is defined as

$$[P(d)-P(0)]/[1-P(0)],$$

and may be interpreted as the probability of the occurrence of a tumor at a dose of d, given that no tumor would have occurred in the absence of the dose.

At low dose levels, statistical upper limits on risk estimated using the multistage model are approximately given by q_1^*d, where q_1^* is the 95% statistical upper confidence limit on the parameter q_1. Consequently, upper confidence limits on risk are simply proportional to the dose level. This implies that the use of these limits is roughly equivalent to using a straight line drawn through the data to predict risk.

Although maximum likelihood estimates of risk obtained using this model are thought to be quite uncertain, there is strong support for the point of view that statistical upper confidence limits are unlikely to underestimate the risk from low exposures (Crump, 1985). Therefore, these upper confidence limits are appropriate for use in this analysis. Such limits are applied widely by Federal agencies to set upper limits to carcinogenic risks (USEPA, 1980, OSHA, 1983, and Kimbrough *et al.*, 1984).

Estimates of risk based on animal data must be made to apply to humans. This step is performed by assuming that animal and human risk are equal when doses are measured in milligrams per kilogram body weight per day (mg/kg/day). This approach has been applied by several groups, including the Center for Disease Control (Kimbrough *et al.*, 1984) and the Occupational Safety and Health Administration (OSHA, 1983). On the other hand, the Environmental Protection Agency Carcinogen Assessment Group typically assumes that risks are equal for animals and humans when exposures are measured in milligrams per square meter surface area per day ($mg/m^2/day$). This latter approach normally gives a higher estimated human risk than the mg/kg/day method. The mg/kg/day approach is used in this document because limited data from chemicals for which both animal and human data are available suggest that this approach gives better estimates of human risk than the $mg/m^2/day$ method (Crump *et al*, 1985). Human doses in mg/kg/day are calculated by dividing total doses in mg/kg by 25,500 days (70 years).

Frequently there are several data sets from which risk estimates can be developed; data may be available on more than one animal species, on both males and females, and for several tumor types. When this is the case risk estimates generally will be developed for the present study from the data set that provides the highest estimates of risk (specifically the data set for which the 95% statistical upper bound on risk is the largest). This rule may be modified if the study giving the highest risk is clearly toxicologically inferior.

2.5. Potency Assessment Results for Carcinogenesis

Potency estimates were derived for a total of twenty cancer data sets from studies of Kimbrough *et al.* (1975) [Aroclor 1260], National Cancer Institute (1978) (including data from reevaluations of this study by Morgan *et al.*, 1981 and Ward, 1985) [Aroclor 1254], Norback and Weltman (1985) [Aroclor 1260], and Schaeffer *et al.* (1984) [Clophen A60], and various combinations of data from these studies using the methodology described in the previous section. These estimates are shown in Table 2-2. The value of 0.639 $(mg/kg/day)^{-1}$ was selected for estimating risk in this assessment. This value was derived from combined data on total liver tumors in the Kimbrough *et al.* and Norback and Weltman studies and was the highest statistical 95% upper limit on potency of the twenty such potency values calculated (except that use of liver tumors from the Norback and Weltman studies alone gave a slightly higher potency than use of the combined data).

For the relatively low exposures which are encountered in environmental settings, the extra risk of cancer from PCBs is estimated by simply multiplying the potency estimate of 0.639 by the lifetime average dose of PCBs in mg/kg/day. For example, the estimated extra risk of cancer from lifetime ingestion of 0.0001 mg/kg/day PCBs is estimated as (0.639)(0.0001) = 0.0000639, or 64 per million.

EPA (1983) estimated a potency value of 4.34 $[mg/kg/day]^{-1}$, using the data of Kimbrough *et al.*, 1975. This potency value is about seven times higher than the value of 0.639 $[mg/kg/day]^{-1}$. This difference is due mainly to the fact that EPA used the body surface area method (specifically, mg/m^2 body surface area/day) for converting doses from animals to humans rather than mg/kg/day. Data on the correlation between animal and human carcinogenicity data indicate that the mg/kg/day approach applied herein generally provides more accurate estimates of human risk than use of mg/m^2/day (Crump *et al.*, 1985). A more extensive analysis of animal and human data being performed by K. S. Crump and Co. for EPA supports this finding. Estimates of risk provided in this analysis from specified exposures can be converted to those that would result from applying the EPA approach by multiplying the risk estimates by 4.34/0.639 = 6.8.

Quantitative Assessment of Potency of PCBs

The PCBs found at the OMC site are generally similar in chlorine content to that of Aroclors 1242 and 1248. However, because of the lack of data on Aroclors 1242 and 1248, risk estimates were derived from studies on Aroclor 1260, which is more highly chlorinated. In general, PCB toxicity appears to vary with both the chlorine content and the amount of isomers with a specific spatial configuration. In the only study in which the carcinogenicity of PCB congeners was directly compared, Clophen A60 (comparable to Aroclor 1260 in chlorine content) and Clophen A30 (comparable to Aroclor 1242) were tested. Exposure to Clophen A60 resulted in a significant increase in liver cancers, while exposure to Clophen A30 did not significantly increase liver cancers. Since the risk estimates utilized in the assessment are based on the carcinogenicity of Aroclor 1260, they may overestimate the carcinogenic risk from the PCBs at the OMC site.

Table 2-1

Summary of Lowest No Observed Effect Levels (NOELs) for Noncarcinogenic Effects

Type of Effect (mg/kg/day)				
Systemic	Reproductive	Teratogenic	Fetotoxic	Immunologic
0.1[a]	0.033[b]	0.167[b]	0.017[b]	0.087[c]

[a]McNulty, W. P. (1976). Primate study. *Proceedings of the National Conference on Polychlorinated Biphenyls.* Sponsored by U. S. Environmental Protection Agency.
Bell, M. (1976). Ultrastructural features of gastric mucosa and sebaceous glands after ingestion of Aroclor 1242 by Rhesus monkeys. *Proceedings of the National Conference on Polychlorinated Biphenyls.* Sponsored by U. S. Environmental Protection Agency. pp. 334-335.

[b]Allen, J., Barsotti, D., Lambrecht, L., and Van Miller, J. (1979). Reproductive effects of halogenated aromatic hydrocarbons on non-human primates. *Annals of New York Academy of Sciences* **320**:419-425.

[c]Thomas, P. and Hinsdill, R. (1978). Effect of polychlorinated biphenyls on the immune responses of Rhesus monkeys and mice. *Toxicology and Applied Pharmacology* **44**:41-51.

Table 2-2

Cancer Potency Estimates Based on the Multistage Model

Data Set	Potency Estimates $[mg/kg/day]^{-1}$ q_1	q_1^*	p-value	Extra Risk at 10^{-6} MLE	95% Lower Limit
1. N/W[a]: female, liver carcinoma	1.24E-1	1.78E-1	~1	8.05E-6	5.62E-6
2. N/W: female, liver adenocarcinoma	1.71E-1	2.37E-1	~1	5.84E-6	4.21E-6
3. N/W: female, liver neoplastic nodules	5.48E-3	2.38E-2	~1	1.82E-4	4.21E-5
4. N/W: female, liver total tumors	7.52E-1	1.09E0	~1	1.33E-6	9.15E-7
5. N/W: female, cholangioma	1.78E-1	2.51E-1	~1	5.62E-6	3.98E-6
6. N/W: male, liver neoplastic nodules	2.76E-2	5.32E-2	~1	3.62E-5	1.88E-5
7. N/W: male, liver total tumors	3.96E-2	6.96E-2	~1	2.53E-5	1.44E-5
8. N/W: male, cholangioma	8.70E-2	1.38E-1	~1	1.15E-5	7.25E-6
9. NCI[b]: male, liver carcinoma/adenoma	2.77E-2	7.77E-2	0.87	3.61E-5	1.29E-5
10. NCI[b]: female, liver carcinoma/adenoma	2.49E-2	4.79E-2	0.25	4.02E-5	2.09E-5
11. NCI[b]: male/female, liver carcinoma/ adenoma	2.29E-2	5.58E-2	0.41	4.36E-5	1.79E-5
12. NCI[c]: male/female, gastric adeno-carcinoma	1.46E-2	2.67E-2	0.45	6.84E-5	3.74E-5
13. NCI: male, all malignancies	0	1.35E-1	0.18	6.61E-3	7.40E-6
14. NCI: female, all malignancies	4.05E-2	1.23E-1	0.03	2.47E-5	8.12E-6
15. NCI: male/female all malignancies	7.54E-2	1.25E-1	0.79	1.33E-5	7.97E-6
16. Kimbrough[d]: female, liver carcinoma	2.93E-2	4.04E-2	~1	3.41E-5	2.48E-5
17. Kimbrough: female, liver neoplastic nodules	3.15E-1	3.66E-1	~1	3.17E-6	2.73E-6
18. Kimbrough: female, liver total tumors	5.14E-1	6.06E-1	~1	1.95E-6	1.65E-6
19. N/W & Kimbrough[e]: female, liver total tumors	5.50E-1	6.39E-1	0.14	1.82E-6	1.57E-6
20. Schaeffer[f]: male, liver total tumors	4.03E-1	4.81E-1	~1	2.48E-6	2.08E-6

Table 2-2 (continued)

Cancer Potency Estimates Based on the Multistage Model

[a] Norback, D. H. and Weltman, R. H. (1985). Polychlorinated biphenyl induction of hepatocellular carcinoma in the Sprague-Dawley rat. *Environmental Health Perspectives* 1:134-143.

[b] National Cancer Institute (1978). Bioassay of Aroclor 1254 for possible carcinogenicity. CAS No. 27323-18-8. NCI-CG-TR-38. Reevaluated by: Ward, J. M. (1985). Proliferative lesions of the glandular stomach and liver in F344 rats fed diets containing Aroclor 1254. *Environmental Health Perspectives* 60:89-95.

[c] National Cancer Institute (1978). Bioassay of Aroclor 1254 for possible carcinogenicity. CAS No. 27323-18-8. NCI-CG-TR-38. Reevaluated by: Morgan, R. W., Ward, J. M. and Hartman, P. E. (1981). Aroclor 1254-induced intestinal metaplasia and adenocarcinoma in the glandular stomach of F344 rats. *Cancer Research* 41:5052-5059.

[d] Kimbrough, R. D., Squire, R. A., Linder, R. E., *et al.* (1975). Induction of liver tumors in Sherman strain female rats by polychlorinated biphenyl Aroclor 1260. *Journal of the National Cancer Institute* 55(6):1453-1459.

[e] Combination of data from Norback and Weltman (1985) and Kimbrough *et al.* (1975).

[f] Schaeffer, E., Greim, H., and Goessner, W. (1984). Pathology of chronic polychlorinated biphenyl feeding in rats. *Toxicology and Applied Pharmacology* 75:278-288.

3. Assessment of Fish PCB Levels, and the Numbers of Fishermen and Their Catch in Lake Michigan

3.1. Introduction

In 1971, a U. S. Environmental Protection Agency study discovered elevated levels of PCBs in Lake Michigan fish. Concentrations of 15 ppm in lake trout were found, and concentrations in excess of the then 5 ppm FDA standard were detected in trout and salmon greater than twelve inches in length.

The U. S. Food and Drug Administration (FDA) established a temporary tolerance for PCB concentrations in fish and shellfish of 5 ppm in 1973. The interstate transport of fish containing PCBs greater than 5 ppm in the edible portion was also prohibited. In 1977, the FDA proposed a new tolerance limit of 2 ppm. This new limit was finally established in August of 1984.

After the initial discovery of PCBs in Lake Michigan fish, numerous government agencies started monitoring PCB concentrations in important fish species. The states of Illinois, Indiana, Michigan, and Wisconsin, as well as the Federal Government began monitoring programs.

By the late 1970s it was generally accepted that the PCBs bioaccumulate in direct correlation with fish age when the PCB water concentration remains constant. Not only do PCBs bioaccumulate in the fatty tissue of the organisms that consume them, they also biomagnify in the food chain, that is at each step in the food chain, from microorganisms to fish to man, the PCB concentrations increase.

Studies of lake trout and coho salmon conducted between 1972 and 1974 found PCB levels between 7 and 20 ppm. Based on these elevated levels when compared to the FDA tolerance of 5 ppm, several states, at that time, banned or restricted the sale of certain fish.

A large number and variety of fish have been caught in Lake Michigan (see Figure 3-1). However, since only a few species of fish are caught and consumed in large numbers, this analysis will focus only on those fish categories. Fish from the whitefish, bloater, and lake herring groups (coregonid fishes) are historically the least contaminated fish in the lake. Mean PCB levels for this fish group were 2 ppm in 1979. In addition, this fish group is insignificant to sport fishery and is considered rare in Lake Michigan. Even though bloaters are not analyzed in this report, they are particularly useful for contaminant evaluation as they are essentially nonmigratory and reflect local contamination conditions.

Young yellow perch are zooplankton feeders, whereas adults eat sculpins, smelt, amphipods, chironomid larva and leeches. The bulk of fish caught in coastal waters in Illinois is the yellow perch. The yellow perch also have historically low PCB levels, and 1984 data indicate levels from 0.1 - 0.39 ppm. Yellow perch are a popular commercial fish and are carefully monitored for PCBs in interstate commerce. For this reason, the yellow perch are not included in this analysis.

Lake trout are used in this analysis, since they provide an estimate of contamination levels in a long lived predatory species which is also essentially nonmigratory, although they have been reported to travel distances of over 100 miles. The lake trout contain more fat than the salmon, and combined with their long life (up to 20 years), and feeding patterns, reported PCB contamination levels are the highest of any Lake Michigan fish. The lake trout have been monitored for PCB body burdens since 1970, and analysis of this data indicates a decline from a maximum of 22.9 ppm in 1974 to 5.63 ppm in 1983 (DeVault, 1985) (see Figure 3-2).

Salmon were chosen for study because of their popularity as a sport fish, rapid growth rate, and migratory behavior. Salmon move about the nearshore and open water areas while maturing and are exposed to contaminants from numerous sources. The salmon is a fast growing terminal predator, consuming large quantities of alewife and other forage fish. They accumulate PCB through direct absorption from the water and from their food chain. Their three-year life span provides an indication of current contamination conditions. Veith (1975) found coho salmon PCB levels as high as 17.3 ppm in fish captured in 1971, but by 1980, PCB levels had dropped to below the FDA limit of 2 ppm (DeVault, 1985). The PCBs detected in 1980 coho salmon most closely resembled Aroclor 1254.

There have been numerous attempts to model the reduction of PCBs in fish tissue (Rodgers and Swain, 1983), and to assess trends in PCB contamination in fish flesh (DeVault and Weishaar, 1984; DeVault, 1985). Rather than using these historical trends or modeling to assess the PCB levels, the most recent data on fish contamination were collected and analyzed and used in this analysis. It is of interest to note that many of the models and historical trends predicted PCB levels more elevated in the out years than is actually the case.

3.2. Waukegan Harbor

Over a period of years, efforts were undertaken to capture fish in Waukegan Harbor in hopes of assessing the effects of the harbor on fish PCB contamination. In 1978 (USEPA, 1978), the EPA could only produce samples in two areas of the harbor, at the municipal park shoreline and in Slip #3. Of the fish taken in 1978, none were of the sport fish variety of interest here. However, a black crappie and a minnow had PCB levels in excess of 30 ppm. Again in 1979 (USEPA, 1979), only two areas could be found where fish could be obtained, again the municipal park shoreline and Slip #3, and again no sport fish of interest were included in the fish caught. In that study PCB levels in carp were reported greater than 30 ppm.

On September 26, 1980 (USEPA, 1980), eight fish were caught in Waukegan Harbor, a rainbow trout, carp, largemouth bass, and 5 yellow perch. The carp and bass PCB levels were reported as 131 and 187.4 ppm, respectively. However, on August 14, 1981 (USEPA, 1981), 10 alewives, 3 carp, 2 suckers and 3 yellow perch were captured and analyzed. In that study the carp had an average PCB value of 27.9 ppm, thus it is likely that there was an error in the analysis of the 1980 sample. It is interesting to note that the only "sport" fish PCB data from the harbor were one rainbow trout captured in 1980, and eight yellow perch captured in 1980 and 1981. The PCB level for the trout was 2.0 ppm, and for the perch, 34.0 ppm in 1980, and 1.41 ppm in 1981. Again the data disparity causes suspicion of the 1980 data. It is possible that the sport fish of interest here seldom, if ever, enter Waukegan Harbor.

3.3. Fish Data Analysis

Fish PCB contamination data were gathered from the Illinois Environmental Protection Agency and the Department of Conservation, the Michigan Department of Agriculture, the Indiana Department of Natural Resources, and the Wisconsin Department of Natural Resources. Some 1985 data were available, however, 1984 data were more complete in terms of states reporting and fish available for analysis, and consequently 1984 data were chosen for use in this effort. Tables 3-1 through 3-4 provide the raw data from these states.

A recent study of eight salmonid species was conducted by Masnado for the Lake Michigan waters in Wisconsin (Masnado, 1985). This study was conducted to determine statistically accurate levels of PCBs in an effort to determine any spatial and/or seasonal variation.

For this study, the lake was divided into two discrete basins and Green Bay. The southern basin extends from Sheboygan south to Kenosha and includes the major tributary streams of Sheboygan, Milwaukee, and Root Rivers. The northern lake basin stretches from Washington Island to the town of Cleveland in Sheboygan County. The small tributary streams of Reibolts, Heins, and Hibbards are included in this basin, as well as major tributaries of Ahnapes, Kewaunee, East and West Twin and the Manitowoc rivers. The Green Bay waters extended from Washington Island to Green Bay. In our analysis, here, the Green Bay region is not considered because of its physical separation from Lake Michigan's main basin. The data used here include: for brook trout, the northern, southern and Sheboygan River zone (Tables 3-5, 3-6, and 3-7); for rainbow trout, the main lake basin and the Sheboygan River (Tables 3-8 and 3-9); for coho salmon, the main lake basin (Table 3-10); for the lake trout, the main lake basin (Table 3-11); for the brown trout, the main lake basin and Sheboygan River (Tables 3-12 and 3-13); and for chinook salmon, the northern and southern zone (Tables 3-14 and 3-15).

Note that only two states provide data for the yellow perch, Indiana (3 fish) and Illinois (1 fish). Because of the paucity of data and the fact that the yellow perch has had historically very low PCB levels, they were excluded from this analysis. Since Illinois 1984 data were limited, 1985 data were added to increase the sample size.

These data were analyzed and mean PCB values for each region were assessed. Table 3-16 shows those values. These data were included with the state data of Tables 3-1 through 3-4 and total mean PCB concentrations by fish species by state are shown in Table 3-17. Note that the PCB level for lake trout was 3.72 ppm for 1984. Referring to Figure 3-2, this level is consistent with that predicted by the decay curve calculated by DeVault (1985).

For this analysis the fish data were aggregated by salmon and trout family. The trout is a long lived fish and is less migratory than the salmon. Trout data should represent lake conditions over a longer period of time and more local conditions, whereas the salmon, a short lived fish, is migratory, and should represent current PCB contamination levels, and integrates the lake exposures.

The average PCB levels were calculated for each fish family by state, and the data aggregated. For example, the average PCB concentrations for trout can be calculated by the following equation:

$$PCB\ \bar{x}\ species = \Sigma\ (species)\ (\bar{x}\ species)/total\ \#\ fish.$$

Thus for Wisconsin,

$$PCB\ \bar{x}\ trout = [(122)(2.18)\ brown\ trout + (50)(1.06)\ rainbow\ trout + (147)(3.64)\ lake\ trout + (42)(1.26)\ brook\ trout]/361 = 2.51\ ppm.$$

Table 3-18 arrays these data for both trout and salmon.

The average PCB concentration for 495 trout in Lake Michigan is 2.60 ppm with a range of (0.13 - 20.0) ppm. For 442 salmon the PCB average concentration is 1.14 ppm with a range of (0.02 - 5.04) ppm.

The Masnado (1985) data can be analyzed for the relationship between fish size (length) and PCB concentration. There is a significant relationship between length and concentration for the brook, lake, and brown trout, and both the coho and chinook salmon. There was not a significant relationship between length and PCB concentration for the rainbow trout, however, all values were below the FDA limit of 2 ppm. Table 3-20 shows the fish length required to reach the FDA limit of 2 ppm for this data set.

3.4. Populations of Lake Michigan Fishermen and Sport Fish Caught

Table 3-19 arrays data for the number of fishermen who fish Lake Michigan, the angler days spent in Lake Michigan, and the total number of trout and salmon caught in the lake. The number of fishermen who

Lake Michigan was estimated by various means. For Michigan, the Fisheries Division of the Michigan Department of Natural Resources estimated the Lake Michigan fishing effort and participation by Michigan licensed anglers (Jamsen, 1985). In 1981 there were 2,637,000 angler days and 349,000 anglers, or each angler spent 7.55 average days fishing in Lake Michigan for all species of fish contained within the lake.

Michigan has stopped estimating the fish catch data, but there are data available from the 1974 Michigan Department of Natural Resources Annual Sport Fishing Survey. From that survey, 381,000 fishermen caught 1,874,320 trout and salmon. Therefore, if we assume that the same ratios hold in 1981 as in 1974, then we can estimate the 1981 catch as 1,705,631 fish. Jamsen estimated that salmon accounted for 69% of the Great Lakes open-water salmonid catch with nearly equal numbers of coho and chinook salmon represented. Lake trout, steelhead, and brown trout accounted for 19%, 7%, and 5% of the total, respectively. Using these statistics, estimates of 528,700 trout and 1,176,800 salmon taken in 1981 by Lake Michigan fishermen, can be projected.

Data for the State of Wisconsin were received from Michael Hanson of the Wisconsin Department of Natural Resources. Mr. Hanson provided a table on Wisconsin's Lake Michigan Sport Fishery Summary, 1969-1985. From that table, 3,777,572 angler hours were consumed in fishing for trout and salmon. Mr. Hanson estimated the number of licensed fishermen for Lake Michigan in the state of Wisconsin as 229,893 although he indicated that this number was incomplete. Based on Hanson's estimate of licensed fishermen in 1982-1985, 240,000 Lake Michigan fishermen can be projected. In a phone conversation with Mr. Hanson, he suggested using a 4-hour fishing day to convert angler hours to angler days. This conversion yields 944,000 angler days for Wisconsin fishermen.

Data for Indiana were obtained from a creel survey (Meade, 1984). Expanded data representing four types of sport fishing (boat, shoreline, warm water discharge, and stream) were combined to obtain a summary of sport fishing activity monitored May through December, 1984. A total fishing effort of 735,734 angler hours (183,900 angler days using Hanson estimate) produced 276,810 fish. The total harvest consisted of 177,681 yellow perch (64.2%), 34,224 steelhead (12.4%), 29,946 coho (10.8%), 29,109 chinook (10.5%), 3,585 lake trout (1.3%) and 2,265 brown trout (0.8%).

For Illinois (Baur and Rogers, 1985) there are 1,351,901 total anglers who fish in Illinois waters, including the waters of Lake Michigan. Anglers in Illinois fished a total of 40,093,005 angler days, and of those total fishing days, 3,569,242 were in the waters of Lake Michigan. The number of days fished per angler is 29.7, however, because of the expense of fishing in Lake Michigan, the days fished per angler will likely be less. From the Baur and Rogers report, there is no direct way to estimate the number of fishermen from Illinois who fish in Lake Michigan. In order to estimate this number, we have assumed that the average angler days on the lake is similar to those for the other three states, and have estimated that 634,000 fishermen from Illinois fish in Lake Michigan. The number of fish caught in Lake Michigan is taken directly from the Baur and Rogers report, that is 595,800 trout and 1,075,000 salmon. Baur and Rogers caution that the number of fish caught was probably overestimated by fishermen.

Assuming there are 1,257,000 fishermen who fish Lake Michigan, we can estimate the population who eat fish from the lake. In concert with Humphrey (1976) we have assumed that each fisherman shares his catch with two other people. Thus the fish eating population becomes 3,771,000 people.

3.5. Pounds of Fish Consumed in an Average Diet

The pounds of fish caught in Lake Michigan were estimated by the following equation:

$$\text{pounds fish} = (\#\ \text{trout})(\text{average weight}) + (\#\ \text{salmon})(\text{average weight}).$$

From Table 3-19 there are 1,347,000 trout and 2,804,000 salmon. The average weight of trout and salmon is calculated using the following equation:

$$\overline{\text{Wgt}}\ \text{species} = \Sigma\ (\#\ \text{fish})(\text{average weight fish})/\text{total fish}$$

and for trout,

$$\begin{aligned}\overline{\text{Wgt}}\ \text{species} = {} & (\#\ \text{brook trout})(\text{average weight}) \\ & + (\#\ \text{brown trout})(\text{average weight}) \\ & + (\#\ \text{steelhead/rainbow})(\text{average weight})/\text{total}\ \#\ \text{fish}\end{aligned}$$

where the average weights and fish catch are taken from Wisconsin data.

$\overline{Wgt}$ trout = 6.8 lbs

$\overline{Wgt}$ trout = 9.8 lbs.

Thus the pounds of fish caught in Lake Michigan is as follows:

$$\begin{aligned}\text{pounds fish} &= (\#\ \text{trout})(\text{average weight}) + (\#\ \text{salmon})(\text{average weight}) \\ &= (1{,}347{,}000)(6.8) + (2{,}804{,}000)(9.8) \\ &= 36{,}638{,}800\ \text{lbs fish.}\end{aligned}$$

Since there are 3,771,000 consumers, each consumer has access to 9.72 pounds of fish per year. Again Humphrey (1976) used a 15% loss in total fish weight to arrive at an edible portion of 8.26 pounds.

3.6. PCB Losses in Cooking Lake Michigan Fish

There have been a variety of studies that assessed the reduction in PCBs when cooking Lake Michigan fish. Zabik *et al*. (1979) have found quantitatively, fat losses of 53%, 34%, and 26% when fish were prepared by broiling, roasting or microwave cooking. These data were specifically for lake trout which have high lipid content. The less fatty salmon possibly would have even greater extraction efficiencies; however, lake trout data were used to reduce PCB levels in salmon through cooking. Assume that fish eaters cook their fish equally by broiling, roasting or microwave cooking, then using Zabik *et al*. data, the PCB concentrations can, on the average, be reduced by a factor of 1.65, with an attendant reduction in trout and salmon PCBs as follows:

trout (2.60)/(1.65) = 1.58 ppm

salmon (1.14)/(1.65) = 0.72 ppm.

3.7. Fish Diet PCB Dose

The total catch of sport fish in Lake Michigan is 9,159,600 pounds of trout and 27,479,200 pounds of salmon. Assuming that the average consumer eats fish in the same ratio as they are caught, for the average Lake Michigan fish eater a total year average dose of PCB from eating fish ca- -- calculated. That dose is based on eating 7.5 lbs of fish (3.41 kg) (0.85 kg trout and 2.55 kg of salmon).

The yearly average dose equals

$$\text{dose} = \sum_{\text{fish}} (\text{pounds fish eater})(\bar{x}\ \text{PCB})$$

$$= (0.85)(1.58) + (2.55)(0.69) = 2.90 \text{ mg PCB},$$

the yearly dose for the average eater.

For the average eater, a yearly dose in mg/kg/day can be calculated

$$(2.90 \text{ mg})/70 \text{ kg body weight} = (0.0414)/365 \text{ days}$$

$$= 0.000114 \text{ mg/kg/day, or}$$

$$0.114\ \mu\text{g/kg/day},$$

below the WHO accepted daily intake level of 1 μg/kg/day.

Even for heavy fish eaters, 47 lbs (21.4 kg) (Humphrey, 1976) the average daily dose is:

$$(5.35)(1.58) + (16.05)(0.69) = 19.52 \text{ mg/year}$$

or 0.279 mg/kg using a 70 kg person, or

$$(0.279)/365 \text{ days}) = 0.000764 \text{ mg/kg/day, or } 0.764\ \mu\text{g/kg/day,}$$

again well below the WHO level.

Table 3-1

Illinois 1985 and (1984) Fish Data PCB in ppm

Lake Trout LKTR	Rainbow Trout RBTR	Brown Trout BRTR	Yellow Perch YEPR	Coho Salmon COSM	Chinook Salmon CNSM
0.36*	0.27	0.34*	(0.10)	0.86	0.66*
0.18*	0.33*	0.46*	0.10	0.10	0.48*
0.37*	0.26	0.53*		0.10	0.42*
(0.76)*	0.37	0.81*		0.24	0.28
(1.01)*	0.13	0.77*		0.45	1.30
(0.55)*	0.32	1.08*		0.12	0.96
0.54	(0.13)	(0.38)		0.83	0.49
	(0.26)	(0.26)		0.39	1.04
	0.26	(0.72)			(0.41)
		(0.28)			(0.54)
		(0.92)			(0.27)
		(0.37)			(0.49)
		(1.03)			(2.28)
		(1.08)			(0.23)
		(0.81)			(0.80)
		(0.58)			(0.75)
		(0.79)			(1.20)
		0.66			(1.04)
					(0.95)
					(1.27)
					(1.74)
					(0.15)
					(2.52)
					(0.43)
					(1.04)
					(0.26)
					(0.12)
					0.87

*Waukegan Harbor vicinity.

Table 3-2

Indiana 1984 Fish Data PCB in ppm

Lake Trout #	Lake Trout PCB	Brown Trout #	Brown Trout PCB	Steelhead Trout #	Steelhead Trout PCB	Yellow Perch #	Yellow Perch PCB	Coho Salmon #	Coho Salmon PCB	Chinook Salmon #	Chinook Salmon PCB
5	6.5	4	2.44	5	1.05	1	0.1	5	0.75	5	1.39
5	6.67	5	3.80	5	0.36	1	0.156	5	0.143	5	0.74
5	20.0	5	3.08	5	1.22	1	0.39	5	1.66	5	1.77
5	11.5		3.34		0.88		0.22	5	0.313	5	2.10
	11.16							5	1.25	5	2.38
								4	1.16	5	2.39
								5	0.73	5	1.74
								5	0.87	5	1.82
								5	0.81	5	2.11
									0.85	5	5.04
										5	2.71
											2.20

Table 3-3

Michigan 1984 Fish Data PCB in ppm
Skin On/Off Analysis

Coho		Chinook		King		Lake Trout			
Skin	PCB	Skin	PCB	Skin	PCB	Skin	PCB	Skin	PCB
on	1.30	on	0.85	on	0.71	off	1.20	off	1.35
	0.88		0.52		0.22		1.00		2.18
	1.94		0.88		0.31		1.10		4.30
	1.45		1.70		0.23		1.50		2.55
	1.99		1.87		0.24		2.72		1.27
	1.52		1.25		0.18		1.25		1.59
	1.21		1.58	off	0.66		0.70		1.01
	0.35		1.85		0.51		0.90		0.99
off	0.51	off	0.61		0.20		3.70		0.86
	0.14		0.30		0.31		2.49		1.42
	0.30		0.32		0.13		1.08		2.20
	0.73		0.61		0.83		0.91		1.53
	1.21		0.20	on	0.45		1.75		1.65
	3.06		0.01		0.62		0.75		1.33
	0.64	on	1.26		1.07		0.87		2.88
	0.81		1.33		0.99		0.77		1.40
	0.48		1.48		0.37		2.95		1.11
	0.20		0.93		0.70		1.45		0.76
	0.80		1.35	off	1.13		1.14		0.64
	1.96		1.11		0.68		0.89		1.08
	1.07	off	0.04		0.78		1.12		0.66
			0.02		0.90		0.75		0.83
			0.02		0.71		0.60		0.64
			0.02		0.82		0.66		0.93
			0.11		0.58		0.93		1.53
			0.05				0.82		
			0.78				1.83		
							0.45		
							0.37		
							0.96		

Table 3-4

Wisconsin 1984 Fish Data PCB in ppm.

Rainbow Trout		Brown Trout		Coho Salmon		Chinook Salmon	
#	PCB	#	PCB	#	PCB	#	PCB
1	1.1	1	3.5	1	0.55	1	4.3
1	0.25	2	4.0	1	0.58	1	3.2
1	1.20	1	5.2	1	0.72	1	2.0
1	0.20	1	3.7	3	0.30	1	1.6
	0.69	1	2.5	3	0.24	1	1.7
		1	7.5	3	0.29	1	2.6
		1	2.0	3	0.32	1	2.8
		1	1.6	1	0.40	1	1.0
		1	1.4	1	0.40	1	0.73
		1	1.3	5	0.28	1	0.90
		2	1.4	5	0.21	1	1.60
		2	3.7	1	1.10	1	0.20
		2	3.0	1	1.20	2	0.30
		2	1.2	1	0.70	1	3.60
		3	1.6	1	0.30	1	1.50
		1	1.7	1	0.45	1	3.50
		1	1.5	1	2.30	1	3.50
			2.64	1	1.80	1	2.10
				1	0.95	1	2.70
				1	0.40	1	1.70
				1	0.58	1	3.60
				1	0.72	1	3.60
				5	1.30	1	1.60
				5	0.85	1	1.30
				4	1.30	1	2.60
					0.67		2.18

Table 3-5

1985 Lake Michigan Salmonid PCB Data

Northern Zone
Brook Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB
Lake Michigan	Claybnk Shl	10/22/85	0.26	0.57	29.6	11.65	2.60	0.27
Lake Michigan	Baileys Har	05/30/85	0.40	0.88	31.0	12.20	4.20	0.50
Lake Michigan	Baileys Har	07/16/85	0.55	1.21	34.4	13.54	4.70	0.52
Lake Michigan	Claybnk Shl	10/22/85	0.59	1.30	35.5	13.98	4.90	0.38
Lake Michigan	Baileys Har	04/07/85	0.65	1.43	36.0	14.17	6.20	0.74
Lake Michigan	Baileys Har	07/17/85	0.70	1.54	37.3	14.68	7.40	0.94
Lake Michigan	Hibbards Cr	06/17/85	0.70	1.54	37.5	14.76	7.20	0.40
Lake Michigan	Sturgn Bay	05/07/85	0.66	1.45	38.1	15.00	5.60	0.38
Lake Michigan	Baileys Har	08/16/85	0.88	1.94	39.3	15.47	6.50	1.00
Lake Michigan	Baileys Har	08/16/85	0.77	1.69	40.6	15.98	4.30	0.96
Lake Michigan	Baileys Har	07/12/85			42.8	16.85	6.60	1.30
Lake Michigan	Baileys Har	07/11/85	1.18	2.60	43.4	17.09	6.20	0.89
Lake Michigan	Baileys Har	07/12/85	1.05	2.31	43.6	17.16	8.50	1.10
Lake Michigan	Baileys Har	07/12/85			44.5	17.52	7.40	0.75
Lake Michigan	Baileys Har	07/11/85	1.40	3.08	45.3	17.83	6.00	0.78
Lake Michigan	Baileys Har	07/17/85	1.30	2.86	45.3	17.83	6.30	0.97
Lake Michigan	Baileys Har	07/11/85	1.35	2.97	46.3	18.23	6.40	0.80

Table 3-6

1985 Lake Michigan Salmonid PCB Data

Sheboygan River Zone
Brook Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB
Sheb R	Sheb Harbor	06/19/85	0.20	0.44	25.5	10.04	4.50	1.70
Sheb R	Sheb Harbor	06/19/85	0.20	0.44	25.5	10.04	4.20	2.00
Sheb R	Sheb Harbor	06/19/85	0.31	0.68	26.0	10.24	4.90	2.30
Sheb R	Sheb Harbor	06/19/85	0.21	0.46	26.0	10.24	4.70	2.90
Sheb R	Sheb Harbor	06/19/85	0.22	0.48	26.5	10.43	4.90	1.40
Sheb R	Sheb Harbor	06/19/85	0.26	0.57	26.5	10.43	6.50	2.00
Sheb R	Sheb Harbor	06/19/85	0.27	0.59	28.2	11.10	3.10	0.53
Sheb R	Kohler Dam	09/16/85	0.30	0.66	28.2	11.10	1.50	0.78
Sheb R	Sheb Harbor	06/19/85	0.31	0.68	28.5	11.22	4.40	0.90
Sheb R	Sheb Harbor	06/19/85	0.29	0.64	28.5	11.22	3.80	0.75
Sheb R	Sheb Harbor	06/19/85	0.30	0.66	28.8	11.34	2.70	0.29
Sheb R	Sheb Harbor	06/19/85	0.33	0.73	30.0	11.81	6.00	1.90
Sheb R	Kohler Dam	09/16/85	0.29	0.64	31.0	12.20	1.70	2.60
Sheb R	Kohler Dam	09/16/85	0.37	0.81	32.5	12.80	2.80	3.80
Sheb R	Kohler Dam	09/16/85	0.35	0.77	32.5	12.80	2.60	0.73
Sheb R	Kohler Dam	09/16/85	0.43	0.95	33.0	13.00	3.10	3.00
Sheb R	Kohler Dam	09/16/85	0.51	1.12	35.8	14.10	1.80	1.60
Sheb R	Kiwanis Pk	09/25/85	1.00	2.20	40.0	15.75	3.10	4.00

Table 3-7

1985 Lake Michigan Salmonid PCB Data

Southern Zone
Brook Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB	LIMIT
Lake Michigan	Grid 1901	04/25/85	0.06	0.13	20.9	8.23	2.60	0.77	
Lake Michigan	Grid 1901	04/25/85	0.13	0.29	24.0	9.45	5.00	0.10	<QUANT.
Lake Michigan	Grid 1901	06/27/85	0.30	0.66	27.1	10.67	4.70	1.20	
Lake Michigan	Grid 1901	06/27/85	0.29	0.64	27.1	10.67	5.10	1.40	
Lake Michigan	Grid 1901	06/27/85	0.24	0.53	27.8	10.94	5.00	1.20	
Lake Michigan	Grid 1901	06/27/85	0.31	0.68	28.8	11.34	3.10	0.97	
Lake Michigan	Grid 1901	07/03/85	0.45	0.99	32.0	12.60	5.10	1.40	

Table 3-8

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone
Rainbow Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB	LIMIT
Root R	Sixth St	10/16/85	0.19	0.42	25.9	10.20	2.50	0.84	
Root R	Sixth St	10/16/85	0.28	0.62	27.8	10.94	5.10	1.30	
Root R	Sixth St	10/03/85	0.58	1.28	35.1	13.80	5.70	0.82	
Root R	Sixth St	10/16/85	0.56	1.23	35.4	13.94	6.00	0.45	
Twin West	Two Rivers	04/18/85	0.60	1.32	38.5	15.16	6.90	0.52	
Root R	Sixth St	10/03/85	0.74	1.63	39.4	15.50	7.40	0.10	<QUANT.
Twin West	Two Rivers	04/18/85	0.65	1.43	39.5	15.55	4.70	0.34	
Lake Michigan	Grid 1303	04/18/85	0.65	1.43	39.5	15.55	4.50	0.48	
Lake Michigan	Grid 1104	05/25/85	0.85	1.87	40.4	15.90	6.80	0.63	
Root R	Sixth St	10/16/85	0.85	1.87	42.4	16.61	6.30	0.32	
Root R	Sixth St	10/03/85	1.11	2.44	42.7	16.80	13.00	0.26	
Twin West	Two Rivers	04/18/85	0.85	1.87	42.9	16.89	6.70	0.42	
Lake Michigan	Grid 1303	07/06/85	0.90	1.98	46.5	18.31	1.90	0.10	<QUANT.
Lake Michigan	Grid 2102	06/01/85	1.30	2.86	50.5	19.90	1.60	0.10	<QUANT.
Lake Michigan	Sturgn Bay	04/04/85	2.00	4.40	55.9	22.00	4.40	0.31	
Root R	Sixth St	10/03/85	2.00	4.40	56.6	22.30	9.00	0.35	
Root R	Sixth St	10/03/85	2.23	4.91	56.9	22.40	12.00	0.52	
Twin West	Two Rivers	04/04/85	2.20	4.84	57.5	22.64	6.30	0.67	
Lake Michigan	Grid 1303	07/06/85	2.30	5.06	57.5	22.64	7.80	1.60	
Lake Michigan	Grid 2102	06/01/85	2.20	4.84	57.9	22.80	6.60	0.22	
Root R	Sixth St	10/03/85	2.12	4.66	59.2	23.30	6.80	0.24	
Root R	Sixth St	10/16/85	2.34	5.15	59.6	23.46	7.70	0.32	
Twin West	Two Rivers	04/04/85	2.25	4.95	59.7	23.50	6.20	1.10	
Lake Michigan	Grid 1303	07/06/85	2.50	5.50	63.5	25.00	6.80	0.64	
Lake Michigan	Grid 2002	06/17/85	4.20	9.24	66.0	25.98	20.00	1.70	
Root R	Sixth St	10/03/85	3.56	7.83	67.3	26.50	13.00	0.67	
Lake Michigan	Grid 2002	06/17/85	4.25	9.35	67.3	26.50	14.00	0.94	
Lake Michigan	Grid 2202	07/20/85	2.60	5.72	68.5	26.97	4.70	0.76	
Lake Michigan	Grid 1303	06/19/85	3.90	8.58	71.0	27.95	5.70	2.00	
Lake Michigan	Grid 1303	07/06/85	3.95	8.69	72.5	28.54	4.30	0.87	

Table 3-8 (continued)

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone
Rainbow Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB	LIMIT
Lake Michigan	Whitefish Pt	06/29/85	3.50	7.70	73.5	28.54	1.10	0.40	
Lake Michigan	Grid 2102	09/07/85	4.25	9.35	75.9	29.88	0.10	0.49	
Lake Michigan	Grid 2002	06/10/85	5.10	11.22	76.2	30.00	6.00	1.00	
Lake Michigan	Grid 220	07/20/85	4.70	10.34	79.0	31.10	9.70	0.75	

Table 3-9

1985 Lake Michigan Salmonid PCB Data

Sheboygan River Zone
Rainbow Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB
Sheb R	Sheb Harbor	06/19/85	0.20	0.44	24.2	9.53	4.70	1.60
Sheb R	Sheb Harbor	06/19/85	0.19	0.42	25.7	10.12	3.10	3.30
Sheb R	Sheb Harbor	06/19/85	0.30	0.66	27.0	10 63	7.30	3.30
Sheb R	Kiwanis Pk	09/25/85	0.25	0.55	28.3	11.14	5.00	1.00
Sheb R	Kiwanis Pk	09/25/85	0.50	1.10	33.0	2.99	7.50	2.90
Sheb R	Sheb Harbor	06/19/85	0.74	1.63	34.6	3.62	10.00	4.00
Sheb R	Kiwanis Pk	09/25/85	0.60	1.32	36.5	14.37	5.90	0.50
Sheb R	Kiwanis Pk	09/25/85	0.65	1.43	37.5	14.76	9.10	1.00
Sheb R	Sheb Harbor	06/19/85	1.05	2.31	41.0	16.14	11.00	5.00
Sheb R	Sheb Harbor	06/19/85	1.10	2.42	41.0	1[illegible].14	15.00	4.40
Sheb R	Kiwanis Pk	09/25/85	2.11	4.64	56.3	22.16	1.50	0.80
Sheb R	Kiwanis Pk	09/25/85	2.51	5.52	56.8	22.36	8.90	0.35

Table 3-10

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone
Coho Salmon

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB	LIMIT
Sheb R	Kohler Dam	09/16/85	0.49	1.08	35.1	13.80	6.80	0.99	
Sheb R	Kiwanis Pk	09/25/85	0.55	1.21	36.3	14.28	5.90	1.10	
Sheb R	Kiwanis Pk	09/25/85	0.70	1.54	39.4	15.50	3.60	0.36	
Sheb R	Kiwanis Pk	09/25/85	0.90	1.98	39.5	15.54	0.38	0.82	
Sheb R	Kiwanis Pk	09/25/85	0.75	1.65	39.5	15.55	3.00	0.41	
Sheb R	Kiwanis Pk	09/25/85	0.70	1.54	39.6	15.60	4.00	0.40	
Sheb R	Kiwanis Pk	09/25/85	0.75	1.65	40.0	15.75	2.40	0.46	
Sheb R	Kiwanis Pk	09/25/85	0.80	1.76	41.0	16.14	1.40	0.26	
Sheb R	Kiwanis Pk	09/25/85	0.75	1.65	41.0	16.14	5.30	1.00	
Sheb R	Kiwanis Pk	09/25/85	1.00	2.20	42.8	16.85	3.80	0.51	
Sheb R	Kiwanis Pk	09/25/85	0.95	2.09	43.0	16.93	2.90	0.51	
Sheb R	Kiwanis Pk	09/25/85	0.95	2.09	43.8	17.24	2.20	0.48	
Sheb R	Kiwanis Pk	09/25/85	1.25	2.75	45.1	17.75	6.40	0.25	
Sheb R	Kiwanis Pk	09/25/85	0.91	2.00	46.1	18.15	2.30	0.72	
Lake Michigan	Grid 2202	05/07/85	1.40	3.08	48.5	19.09	4.10	0.43	
Sheb R	Kiwanis Pk	09/25/85	1.70	3.74	50.5	19.88	7.20	0.63	
Sheb R	Kiwanis Pk	09/25/85	1.20	2.64	50.9	20.04	0.30	0.10	<QUANT.
Sheb R	Kiwanis Pk	09/25/85	1.48	3.26	53.3	20.98	4.20	1.10	
Lake Michigan	Grid 1901	06/04/85	1.60	3.52	54.0	21.26	3.80	0.52	
Lake Michigan	Grid 1901	06/04/85	1.65	3.63	54.1	21.30	5.90	0.90	
Lake Michigan	Grid 2102	06/01/85	1.55	3.41	54.1	21.30	2.40	0.32	
Lake Michigan	Grid 2102	06/01/85	1.50	3.30	54.1	21.30	2.70	0.37	
Lake Michigan	Grid 1901	06/04/85	1.75	3.85	54.4	21.42	5.50	0.86	
Lake Michigan	Grid 1901	06/04/85	1.80	3.96	55.0	21.65	6.00	0.91	

Table 3-10 (continued)

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone
Coho Salmon

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB	LIMIT
Sheb R	Kiwanis Pk	09/25/85	1.66	3.65	56.1	22.09	2.10	0.28	
Lake Michigan	Grid 2102	06/01/85	1.85	4.07	56.4	22.20	3.10	0.50	
Lake Mihcigan	Grid 1901	05/30/85	2.30	5.06	56.7	22.32	8.50	1.30	
Lake Michigan	Grid 2102	06/01/85	1.90	4.18	56.9	22.40	3.90	0.60	
Lake Michigan	Grid 1303	07/06/85	1.70	3.74	57.0	22.44	0.70	0.24	
Lake Michigan	Grid 1901	06/04/85	2.10	4.62	57.1	22.48	8.50	1.10	
Lake Michigan	Grid 2102	06/01/85	1.85	4.07	57.9	22.80	3.00	0.45	
Sheb R	Kiwanis Pk	09/25/85	2.25	4.95	58.0	22.83	3.60	0.38	
Lake Michigan	Grid 1901	06/04/85	1.80	3.96	58.0	22.83	4.40	0.48	
Lake Michigan	Grid 2102	06/01/85	2.15	4.73	58.4	23.00	5.00	0.50	
Lake Michigan	Grid 1303	06/19/85	2.45	5.39	58.5	23.03	5.40	0.81	
Lake Michigan	Grid 1303	06/25/85	2.30	5.06	58.7	23.11	3.20	0.52	
Sheb R	Kiwanis Pk	09/25/85	1.92	4.22	58.9	23.19	2.50	1.40	
Lake Michigan	Grid 1901	06/04/85	2.30	5.06	58.9	23.19	6.00	0.92	
Sheb R	Kiwanis Pk	09/25/85	2.10	4.62	59.0	23.23	2.10	0.63	
Lake Michigan	Grid 1303	06/19/85	2.40	5.28	59.0	23.23	6.10	0.78	
Lake Michigan	Grid 1901	06/04/85	2.40	5.28	59.0	23.23	8.40	1.40	
Lake Michigan	Grid 2102	07/20/85	2.00	4.40	59.0	23.23	3.00	0.56	
Lake Michigan	Grid 2102	06/01/85	2.20	4.84	59.9	23.60	5.10	0.74	
Lake Michigan	Grid 2102	06/01/85	2.35	5.17	60.5	23.80	8.00	1.10	
Lake Michigan	Grid 1303	06/19/85	2.35	5.17	60.5	23.82	4.90	0.70	
Lake Michigan	Grid 1303	07/06/85	2.10	4.62	60.5	23.82	4.70	1.10	
Sheb R	Kiwanis Pk	09/25/85	1.82	4.00	60.7	23.90	1.00	0.42	

Table 3-10 (continued)

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone
Coho Salmon

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB	LIMIT
Lake Michigan	Grid 1303	07/06/85	2.70	5.94	60.8	23.94	3.20	0.63	
Sheb R	Kiwanis Pk	09/25/85	2.25	4.95	61.0	24.02	1.70	0.28	
Lake Michigan	Grid 1303	08/08/85	2.93	6.45	61.2	24.09	4.90	0.73	
Lake Michigan	Grid 1502	08/09/85	2.40	5.28	61.5	24.21	8.20	1.90	
Sheb R	Kiwanis Pk	09/25/85	2.60	5.72	62.0	24.41	1.70	0.37	
Sheb R	Kiwanis Pk	09/25/85	2.70	5.94	62.0	24.41	2.70	0.72	
Lake Michigan	Grid 2102	06/01/85	2.80	6.16	62.5	24.60	8.50	1.50	
Sheb R	Kiwanis Pk	09/25/85	3.15	6.93	63.0	24.80	3.60	2 70	
Sheb R	Kiwanis Pk	09/25/85	3.30	7.26	64.0	25.20	2.00	0.68	
Lake Michigan	Grid 2102	06/01/85	2.90	6.38	64.0	25.20	8.20	1.00	
Lake Michigan	Grid 1502	08/09/85	3.30	7.26	64.0	25.20	6.70	1.70	
Lake Michigan	Grid 1502	08/09/85	3.15	6.93	65.5	25.79	2.20	0.62	
Lake Michigan	Grid 1303	08/08/85	3.24	7.13	65.5	25.83	6.10	1.10	
Lake Michigan	Grid 1303	07/15/85	3.70	8.14	66.0	25.98	7.70	1.70	
Lake Michigan	Grid 2102	07/20/85	3.10	6.82	66.0	25.98	7.20	1.20	
Lake Michigan	Grid 2102	07/20/85	3.00	6.60	66.0	25.98	5.90	1.70	
Sheb R	Kiwanis Pk	09/25/85	3.70	8.14	66.5	26.20	3.40	1.20	
Lake Michigan	Grid 2102	07/20/85	3.70	8.14	67.0	26.38	8.50	2.50	
Sheb R	Kiwanis Pk	09/25/85	3.75	8.25	67.2	26.45	6.00	1.30	
Lake Michigan	Grid 2002	06/10/85	3.65	8.03	67.3	26.50	10.00	1.60	
Lake Michigan	Grid 2102	07/20/85	4.10	9.02	70.0	27.56	9.30	2.90	

Table 3-11

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone

Lake Trout

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 2003	06/17/85	0.22	0.48	29.4	11.57	3.80		0.62
LK MICH	GRID 2003	06/17/85	0.25	0.55	30.3	11.93	5.00		0.54
LK MICH	GRID 1705	08/08/85	0.21	0.46	30.7	12.10	4.90		0.50
LK MICH	GRID 1705	08/08/85	0.21	0.46	31.0	12.20	2.40		0.43
LK MICH	GRID [illegible]503	04/24/84	0.28	0.62	32.0	[illegible]	5.10		0.62
LK MICH	GRID 1104	10/16/8[illegible]	0.30	0.66	33.1	[illegible]	3.60		0.88
LK MICH	GRID 2003	06/17/85	0.35	0.77	33.7	13.27	6.10		0.56
LK MICH	GRID 1705	08/08/85	0.28	0.62	34.3	13.50	4.00		0.54
LK MICH	GRID 1705	08/08/85	0.48	1.06	38.6	15.20	4.90		1.20
LK MICH	GRID 1303	07/30/85	0.55	1.21	39.1	15.39	6.40		0.63
LK MICH	GRID 1303	07/30/85	0.55	1.21	39.3	15.47	6.40		0.68
LK MICH	GRID 1705	08/08/85	0.52	1.14	39.4	15.50	5.20		0.58
LK MICH	GRID 1303	07/30/85	0.55	1.21	39.4	15.51	6.00		0.64
LK MICH	GRID 1303	07/30/85	0.62	1.36	39.5	15.55	7.00		0.70
LK MICH	GRID 1303	07/30/85	0.61	1.34	39.8	[illegible].67	0.73		0.79
LK MICH	GRID 1705	08/08/85	0.51	1.12	39.9	[illegible].70	6.10		0.83
LK MICH	GRID 1303	07/30/85	0.61	1.34	40.1	[illegible].79	4.50		0.55
LK MICH	GRID 1303	07/30/85	0.72	1.58	41.6	16.38	5.20		0.66
LK MICH	GRID 1303	07/30/85	0.70	1.54	42.3	16.65	7.10		0.96
LK MICH	GRID 1303	07/30/85	0.75	1.65	42.4	16.69	8.00		0.95
LK MICH	GRID 1705	08/08/85	0.64	1.41	42.7	16.80	6.80		0.78
LK MICH	GRID 1303	07/30/85	0.78	1.67	43.1	16.97	8.40		1.20
LK MICH	GRID 1303	07/30/85	0.80	1.78	44.1	17.36	6.10		0.70
LK MICH	GRID 1303	07/06/85	1.20	2.64	45.9	18.09	10.00		1.20
LK MICH	GRID 1204	03/22/85	1.00	2.20	46.5	18.30	3.60		0.45
LK MICH	GRID 1303	07/30/85	1.01	2.22	46.9	18.46	7.20		0.84
LK MICH	GRID 1303	07/30/85	1.04	2,29	47.2	18.58	5.40		0.87
LK MICH	GRID 1705	08/08/85	0.98	2.16	47.8	18.80	9.80		1.50
LK MICH	STURGN BAY	06/17/85	1.30	2.86	51.0	20.07	8.90		1.20
LK MICH	GRID 2102	07/20/85	1.80	3.96	51.0	20.08	12.00		2.80
LK MICH	GRID 1303	07/06/85	1.50	3.30	52.0	20.47	12.00		1.40
LK MICH	GRID 1303	07/06/85	1.55	3.41	52.0	20.47	9.30		1.10
LK MICH	GRID 1705	08/08/85	1.33	2.93	52.1	20.50	12.00		1.40
LK MICH	GRID 1705	08/08/85	1.40	3.08	52.8	20.80	15.00		1.50
LK MICH	GRID 1705	08/08/85	1.30	2.86	53.3	21.00	12.00		1.00
LK MICH	GRID 1502	08/10/85	1.40	3.08	53.5	21.06	3.40		0.76
LK MICH	GRID 2102	06/01/85	1.80	3.96	54.9	21.60	16.00		2.70
LK MICH	STURGN BAY	06/17/85	2.00	4.40	55.5	21.85	13.00		1.50
LK MICH	GRID 1303	07/06/85	1.85	4.07	55.5	21.85	12.00		1.00
LK MICH	GRID 1502	08/10/85	1.80	3.98	55.5	21.85	11.00		1.10
LK MICH	GRID 1303	07/06/85	1.96	4.31	56.0	22.04	13.00		1.30
LK MICH	GRID 1705	08/08/85	1.60	3.52	56.1	22.10	12.00		1.40
LK MICH	GRID 1705	08/08/85	1.50	3.30	56.4	22.20	8.20		1.60
LK MICH	GRID 1303	07/06/85	1.85	4.07	56.5	22.24	5.40		1.30
LK MICH	GRID 1303	07/06/85	1.95	4.29	56.5	22.24	12.00		1.30
LK MICH	GRID 805	10/22/85	2.00	4.40	56.9	22.40	11.00		1.40
LK MICH	GRID 1303	07/08/85	2.00	4.40	56.9	22.40	14.00		1.50
LK MICH	GRID 1502	08/10/85	1.55	3.41	57.0	22.44	9.00		1.10
LK MICH	GRID 2102	06/01/85	1.75	3.85	57.4	22.60	14.00		1.70

Table 3-11 (continued)

WATERBDY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 2102	08/01/85	2.10	4.62	57.4	22.60	14.00		1.80
LK MICH	GRID 2102	06/01/85	1.90	4.18	57.4	22.60	12.00		1.50
LK MICH	GRID 905	10/22/85	2.00	4.40	57.5	22.6	14.00		2.30
LK MICH	GRID 2102	06/01/85	2.05	4.51	57.9	22.8	12.00		1.90
LK MICH	GRID 1104	06/07/85	1.75	3.85	59.7	23.50	8.00		1.10
LK MICH	GRID 1502	07/17/85	2.05	4.51	60.1	23.67	12.00		1.70
LK MICH	GRID 2102	09/07/85	2.45	5.39	60.6	23.86	12.00		2.00
LK MICH	GRID 905	10/22/85	2.00	4.40	60.8	23.94	9.90		2.40
LK MICH	GRID 1701	07/25/85	2.15	4.73	61.0	24.00	15.00		2.50
LK MICH	GRID 905	10/22/85	2.00	4.40	61.2	24.09	14.00		2.10
LK MICH	GRID 2102	06/01/85	2.90	6.38	61.5	24.20	18.00		2.50
LK MICH	GRID 1303	07/06/85	2.30	5.06	61.5	24.21	12.00		1.50
LK MICH	GRID 1502	08/10/85	2.15	4.73	61.5	24.21	12.00		1.20
LK MICH	GRID 905	10/22/85	2.75	6.05	62.0	24.41	11.00		2.70
LK MICH	GRID 905	10/22/85	2.75	6.05	62.0	24.41	12.00		2.40
LK MICH	GRID 1303	07/06/85	2.75	6.05	62.0	24.41	18.00		2.40
LK MICH	GRID 2102	07/20/85	2.30	5.06	62.0	24.41	12.00		2.50
LK MICH	GRID 1502	07/17/85	2.05	4.51	62.0	24.41	15.00		1.90
LK MICH	GRID 1502	08/10/85	2.50	5.50	62.5	24.61	13.00		2.80
LK MICH	GRID 905	10/22/85	2.50	5.50	62.8	24.72	16.00		4.40
LK MICH	GRID 1303	07/06/85	2.70	5.94	63.0	24.80	18.00		2.40
LK MICH	GRID 1705	08/08/85	2.32	5.10	63.0	24.80	15.00		3.10
LK MICH	GRID 1502	08/10/85	4.65	10.23	63.0	24.10	21.00		[illegible].20
LK MICH	STURGN BAY	06/17/85	2.70	5.94	63.2	24.88	17.00		[illegible].10
LK MICH	STURGN BAY	08/14/85	2.23	4.91	64.1	25.24	12.00		3.10
LK MICH	GRID 905	10/22/85	2.50	5.50	64.5	25.39	10.00		3.10
LK MICH	GRID 905	10/22/85	3.50	7.70	64.5	25.39	12.00		2.50
LK MICH	GRID 1303	07/05/85	3.25	7.15	64.5	25.39	17.00		2.60
LK MICH	GRID 1303	07/06/85	2.55	5.61	64.7	25.47	14.00		2.00
LK MICH	GRID 905	10/22/85	2.40	5.28	65.5	25.79	14.00		3.30
LK MICH	GRID 905	10/22/85	3.50	7.70	66.0	25.98	15.00		3.90
LK MICH	GRID 2202	07/20/85	2.90	6.38	66.0	25.98	14.00		4.00
LK MICH	GRID 1303	07/06/85	3.05	6.71	66.0	25.98	19.00		3.10
LK MICH	GRID 2102	06/01/85	3.20	7.04	66.0	25.98	19.00		4.40
LK MICH	GRID 1502	06/21/85	2.27	4.99	66.0	25.98	16.00		3.60
LK MICH	GRID 2102	06/01/85	2.85	6.27	66.0	26.00	16.00		3.00
LK MICH	GRID 2102	06/01/85	3.35	7.37	66.5	26.18	18.00		3.30
LK MICH	GRID 905	10/22/85	2.75	6.05	67.0	26.38	12.00		3.40
LK MICH	GRID 1303	07/06/85	3.20	7.04	67.0	26.38	18.00		3.80
LK MICH	GRID 2102	06/01/85	3.00	6.60	67.0	26.38	18.00		5.80
LK MICH	GRID 1303	07/06/85	3.10	6.82	67.5	26.57	18.00		3.10
LK MICH	GRID 2102	06/01/85	3.10	6.82	67.5	26.57	22.00		3.30
LK MICH	GRID 1303	07/08/85	3.25	7.15	67.8	26.68	26.00		5.00
LK MICH	GRID 905	10/22/85	3.00	6.60	68.0	26.77	16.00		2.30
LK MICH	GRID 2102	06/01/85	3.50	7.70	68.0	26.77	23.00		4.80
LK MICH	GRID 1502	08/10/85	3.05	6.71	68.0	26.77	16.00		3.20
LK MICH	GRID 1502	07/17/85	3.50	7.70	68.5	26.97	20.00		4.50
LK MICH	GRID 1502	08/10/85	3.95	8.69	68.5	26.97	26.00		8.00
LK MICH	GRID 1502	08/10/85	3.25	7.15	68.5	26.97	17.00		4.20

Fish PCB Levels

Table 3-11 (continued)

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 905	10/22/85	3.50	7.70	69.5	27.36	12.00		2.80
LK MICH	GRID 1502	08/10/85	3.20	7.04	69.5	27.36	17.00		3.30
LK MICH	GRID 1502	07/17/85	3.50	7.70	70.0	27.56	19.00		2.60
LK MICH	GRID 2102	06/01/85	3.60	7.92	70.5	27.76	19.00		6.90
LK MICH	GRID 1503	07/17/85	3.15	6.93	70.5	27.76	16.00		3.00
LK MICH	GRID 2102	06/01/85	3.70	8.14	71.0	27.95	20.00		4.30
LK MICH	GRID 905	10/22/85	3.75	8.25	71.5	28.15	14.00		3.60
LK MICH	GRID 2102	06/01/85	3.90	8.58	71.5	28.15	23.00		9.00
LK MICH	GRID 1502	07/17/85	3.90	8.58	71.5	28.15	13.00		4.80
LK MICH	GRID 1502	07/17/85	3.60	7.92	71.5	28.15	18.00		4.80
LK MICH	GRID 905	10/22/85	4.00	8.80	72.0	28.35	7.90		3.70
LK MICH	GRID 905	10/22/85	4.00	8.80	72.5	28.54	13.00		4.20
LK MICH	GRID 1502	07/17/85	4.45	9.79	72.5	28.54	26.00		6.30
LK MICH	GRID 1502	08/10/85	4.10	9.02	72.5	28.54	21.00		4.40
LK MICH	GRID 1502	07/17/85	3.60	7.92	73.0	28.74	14.00		3.50
LK MICH	GRID 1502	07/17/85	3.40	7.48	73.0	28.74	17.00		3.30
LK MICH	GRID 1502	06/21/85	.	.	73.5	28.94	24.00		9.70
LK MICH	GRID 1502	08/10/85	4.35	9.57	73.5	28.94	21.00		4.30
STURGN BAY	PORTAGE PK	04/19/85	4.60	10.12	73.7	29.00	19.00		6.30
LK MICH	GRID 2102	06/01/85	4.00	8.80	74.5	29.33	18.00		2.90
LK MICH	GRID 2102	06/01/85	4.50	9.90	76.0	29.92	19.00		8.60
LK MICH	GRID 2102	07/20/85	4.80	10.56	76.0	29.92	21.00		7.30
LK MICH	GRID 1502	07/17/85	4.25	9.35	76.0	29.92	20.00		7.10
LK MICH	GRID 2102	07/20/85	4.30	9.46	76.5	30.12	12.00		4.50
LK MICH	GRID 1502	07/17/85	5.00	11.00	76.5	30.12	24.00		11
LK MICH	GRID 1502	08/10/85	4.40	9.68	76.5	30.12	21.00		5.60
LK MICH	GRID 1503	08/10/85	4.80	10.56	76.5	30.12	21.00		7.30
LK MICH	GRID 2102	06/01/85	4.95	10.89	77.0	30.31	18.00		5.00
LK MICH	GRID 2003	06/17/85	5.60	12.32	77.5	30.51	22.00		6.80
LK MICH	GRID 1204	05/25/85	5.55	12.21	78.0	30.70	22.00		9.80
LK MICH	GRID 2102	06/01/85	5.25	11.55	78.0	30.71	9.00		8.40
LK MICH	GRID 2102	07/20/85	4.90	10.78	78.0	30.71	17.00		8.00
LK MICH	GRID 1204	05/25/85	6.65	14.63	78.5	30.90	24.00		5.70
LK MICH	GRID 1104	05/28/85	4.45	9.79	78.7	31.00	16.00		15
LK MICH	GRID 905	10/22/85	5.00	11.00	79.0	31.10	17.00		4.90
LK MICH	GRID 1303	07/06/85	5.85	12.87	79.0	31.10	21.00		14
LK MICH	GRID 1507	06/21/85	.	.	79.0	31.10	14.00		8.10
LK MICH	GRID 1502	08/10/85	5.16	11.33	79.0	31.10	23.00		5.20
LK MICH	GRID 1303	07/06/85	6.30	13.86	79.5	31.30	22.00		4.90
LK MICH	GRID 1502	07/17/85	5.10	11.22	80.5	31.69	18.00		5.30
LK MICH	GRID 1502	07/17/85	4.90	10.78	81.0	31.89	20.00		7.80
LK MICH	STURGN BAY	05/18/85	6.60	14.52	81.3	32.00	21.00		8.80
LK MICH	GRID 2202	07/20/85	5.80	12.76	82.0	32.28	20.00		8.50
LK MICH	GRID 905	10/22/85	5.75	12.65	83.5	32.87	18.00		6.40
LK MICH	GRID 1502	07/17/85	6.40	14.08	84.5	33.27	25.00		10
LK MICH	GRID 905	10/22/85	6.00	13.20	84.5	33.28	14.00		5.30
LK MICH	GRID 1004	05/25/85	6.20	13.64	86.4	34.00	21.00		17
LK MICH	GRID 1502	07/17/85	6.90	15.18	86.5	34.06	16.00		15
LK MICH	GRID 1502	07/17/85	6.50	14.30	88.0	34.64	22.00		8.00

Table 3-12

1985 Lake Michigan Salmonid PCB Data

Main Lake Basin Zone
Brown Trout

WATERBDY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 2102	06/21/85	0.38	0.84	28.5	11.22	8.60		0.98
LK MICH	GRID 2102	06/21/85	.	.	31.0	12.20	8.30		1.20
LK MICH	GRID 1502	08/09/85	0.55	1.21	34.0	13.38	5.20		2.00
LK MICH	GRID 1502	08/10/85	0.70	1.54	35.0	13.78	9.30		3.50
LK MICH	GRID 805	07/05/85	1.05	2.31	35.7	14.06	13.00		1.50
LK MICH	GRID 1502	06/21/85	0.75	1.65	37.0	14.56	11.00		2.00
LK MICH	GRID 1502	08/10/85	0.75	1.65	38.0	14.96	9.20		1.70
LK MICH	BAILEYS HAR	10/09/85	0.79	1.74	40.0	15.75	3.70		0.48
LK MICH	GRID 1502	06/21/85	1.03	2.27	40.0	15.75	15.00		3.30
LK MICH	BAILEYS HAR	10/02/85	1.10	2.42	41.4	16.30	5.70		0.77
LK MICH	GRID 1502	06/21/85	0.91	2.00	43.0	16.93	16.00		1.70
LK MICH	BAILEYS HAR	09/25/85	1.31	2.88	43.6	17.16	6.90		0.54
LK MICH	BAILEYS HAR	04/07/85	1.45	3.19	45.0	17.72	14.00		1.30
LK MICH	BAILEYS HAR	04/07/85	1.75	3.85	45.3	17.83	20.00		1.10
LK MICH	GRID 905	05/02/85	1.85	4.07	45.8	18.03	21.00		1.10
LK MICH	GRID 1303	07/29/85	1.80	3.96	46.6	18.35	14.00		1.70
LK MICH	BAILEYS HAR	10/09/85	1.25	2.75	47.6	18.75	6.80		1.20
LK MICH	GRID 1303	07/29/85	2.10	4.62	47.8	18.82	14.00		1.10
STURGN BAY	PORTAGE PK	04/09/85	1.05	2.31	47.9	18.87	14.00		3.60
LK MICH	BAILEYS HAR	04/07/85	1.90	4.18	48.0	18.90	15.00		1.70
LK MICH	GRID 1502	07/15/85	2.10	4.62	48.5	19.09	16.00		2.00
LK MICH	LILLY BAY	05/03/85	2.05	4.51	49.0	19.29	17.00		0.93
LK MICH	GRID 1303	07/08/85	1.90	4.18	49.5	19.49	17.00		1.80
LK MICH	GRID 607	04/26/85	1.90	4.18	49.5	19.50	15.00		0.80
LK MICH	BAILEYS HAR	04/07/85	2.00	4.40	49.7	19.57	18.00		1.40
LK MICH	GRID 1502	08/21/85	1.48	3.26	50.0	19.68	16.00		1.80
LK MICH	GRID 1502	06/21/85	1.02	2.24	50.0	19.68	19.00		2.30
LK MICH	BAILEYS HAR	04/07/85	1.85	4.07	50.2	19.76	17.00		1.00
LK MICH	BAILEYS HAR	09/25/85	1.44	3.17	50.3	19.80	7.60		1.40
LK MICH	GRID 1303	07/08/85	2.20	4.84	50.3	19.80	15.00		1.20
LK MICH	BAILEYS HAR	04/07/85	2.05	4.51	51.0	20.08	17.00		.60
LK MICH	GRID 1502	06/21/85	1.82	4.00	51.0	20.08	18.00		2.60
LK MICH	STURGN BAY	04/23/85	1.45	3.19	51.1	20.10	3.00		1.70
LK MICH	BAILEYS HAR	04/07/85	1.80	3.96	51.5	20.28	11.00		1.30
LK MICH	GRID 1502	06/21/85	.	.	51.5	20.28	15.00		1.50
LK MICH	GRID 1502	06/21/85	.	.	51.5	20.28	19.00		1.60
LK MICH	BAILEYS HAR	04/07/85	2.20	4.84	51.8	20.39	18.00		4.30
LK MICH	BAILEYS HAR	04/07/85	2.35	5.17	52.0	20.47	21.00		.70
LK MICH	GRID 2102	06/21/85	2.27	4.99	52.0	20.47	18.00		.80
LK MICH	GRID 1004	06/25/85	2.45	5.39	52.2	20.55	11.00		.80
STURGN BAY	PORTAGE PK	08/29/85	2.40	5.28	52.4	20.63	11.00		3.20
LK MICH	GRID 1402	06/20/85	3.00	8.60	52.4	20.63	1.70		.70
LK MICH	GRID 2102	09/07/85	3.50	7.70	53.0	20.87	10.00		2.20
LK MICH	BAILEYS HAR	10/02/85	2.20	4.84	53.1	20.91	9.00		2.40
LK MICH	GRID 2002	05/18/85	2.52	5.54	53.3	21.00	17.00		1.20
LK MICH	GRID 1502	08/10/85	2.30	5.06	53.5	21.06	10.00		1.10
LK MICH	BAILEYS HAR	09/25/85	2.39	5.26	53.6	21.10	8.50		1.80
LK MICH	GRID 1303	07/08/85	2.80	6.16	54.5	21.46	14.50		1.10
LK MICH	GRID 1502	08/10/85	2.40	5.28	54.5	21.46	9.80		0.91

Table 3-12 (continued)

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	BAILEYS HAR	09/16/85	2.25	4.95	54.8	21.57	7.80		1.90
LK MICH	BAILEYS HAR	04/07/85	3.30	7.26	56.0	22.05	18.00		0.82
LK MICH	GRID 1303	07/29/85	3.10	6.82	56.7	22.32	15.00		1.60
LK MICH	GRID 1303	07/06/85	3.35	7.37	57.0	22.44	16.00		1.70
LK MICH	GRID 1502	08/10/85	3.25	7.15	57.0	22.44	13.00		2.70
LK MICH	GRID 1502	08/10/85	3.45	7.59	57.0	22.44	17.00		2.60
LK MICH	GRID 1502	08/09/85	3.50	7.70	58.0	22.83	16.00		1.40
LK MICH	GRID 1502	08/10/85	3.45	7.59	58.0	22.83	13.00		1.60
LK MICH	GRID 2002	06/10/85	3.45	7.59	58.4	23.00	22.00		1.20
LK MICH	LILLY BAY	06/30/85	4.00	8.80	59.0	23.23	22.00		4.70
LK MICH	GRID 1303	07/29/85	3.60	7.92	59.3	23.35	16.00		1.30
LK MICH	GRID 2102	06/01/85	3.24	7.13	59.4	23.40	20.00		4.00
LK MICH	GRID 1502	08/10/8	3.40	7.48	59.5	23.42	14.00		1.40
STURGN BAY	PORTAGE PK	08/01/85	4.55	10.01	59.8	23.54	14.00		3.90
LK MICH	NORTH BAY	05/28/85	4.15	9.13	60.0	23.62	21.00		4.50
LK MICH	GRID 2002	06/12/85	4.40	9.68	60.0	23.62	24.00		0.93
LK MICH	GRID 1901	06/06/85	3.80	8.36	60.5	23.82	20.00		3.80
LK MICH	GRID 2002	04/25/85	3.45	7.59	61.0	24.00	7.10		2.00
LK MICH	GRID 2002	05/10/85	3.65	8.03	61.0	24.00	23.00		2.80
LK MICH	LILLY BAY	06/28/85	3.80	8.36	61.0	24.02	14.00		1.10
LK MICH	GRID 1502	08/10/85	3.90	8.58	61.0	24.02	14.00		1.70
LK MICH	GRID 1502	08/10/85	3.55	7.81	61.5	24.21	13.00		2.20
LK MICH	GRID 1502	08/10/85	3.45	7.59	61.5	24.21	12.00		1.60
LK MICH	BAILEYS HAR	08/29/85	5.40	11.88	62.5	24.60	21.00		2.60
LK MICH	GRID 1901	05/15/85	3.25	7.15	62.5	24.61	13.00		3.70
LK MICH	GRID 1502	08/10/85	3.70	8.14	62.5	24.61	12.00		1.40
LK MICH	GRID 1502	07/17/85	3.65	8.03	63.5	25.00	13.00		2.30
LK MICH	GRID 1303	07/29/85	3.80	8.36	63.6	25.04	13.00		1.30
LK MICH	GRID 1502	08/10/85	4.25	9.35	64.5	25.39	10.00		2.10
LK MICH	GRID 1502	08/10/85	4.65	10.23	65.0	25.59	17.00		2.20
LK MICH	GRID 1502	08/10/85	4.90	10.78	66.0	25.98	12.00		2.90
LK MICH	GRID 1502	08/10/85	5.10	11.22	66.5	26.18	14.00		3.50
LK MICH	GRID 2002	06/17/85	5.55	12.21	67.5	26.57	20.00		2.10
LK MICH	GRID 1004	04/26/85	4.70	10.34	68.6	27.00	9.20		2.90
LK MICH	BAILEYS HAR	04/07/85	5.15	11.33	69.5	27.36	11.00		5.80
LK MICH	GRID 1502	08/09/85	7.50	16.50	78.5	30.90	16.00		2.30

Table 3-13

1985 Lake Michigan Salmonid PCB Data

Sheboygan River Zone
Brown Trout

Waterbody	Location	Date	Wt Kilo	Wt lb	Lngth CM	Lngth IN	PCT Fat	PCB
Sheb R	Sheb Harbor	06/19/85	0.14	0.31	21.5	8.46	5.30	3.50
Sheb R	Sheb Harbor	06/19/85	0.16	0.35	24.5	9.64	3.90	2.10
Sheb R	Sheb Harbor	06/19/85	0.25	0.55	26.0	10.24	9.40	2.60
Sheb R	Sheb Harbor	06/19/85	0.29	0.64	26.5	10.43	6.80	2.40
Sheb R	Kiwanis Pk	09/25/85	0.70	1.54	35.0	13.78	4.70	3.20
Sheb R	Kiwanis Pk	09/25/85	3.50	7.70	49.0	19.29	7.30	1.50
Sheb R	Kiwanis Pk	09/25/85	1.60	3.52	49.7	19.57	8.60	2.40
Sheb R	Kiwanis Pk	09/25/85	1.95	4.29	50.2	19.76	6.00	2.20
Sheb R	Kiwanis Pk	09/25/85	2.27	4.99	50.5	19.88	9.80	1.90
Sheb R	Kiwanis Pk	09/25/85	2.35	5.17	55.0	21.65	14.00	3.00
Sheb R	Kiwanis Pk	09/25/85	3.50	7.70	55.5	21.85	10.50	2.10
Sheb R	Kiwanis Pk	09/25/85	2.41	5.30	55.6	21.89	7.00	1.60
Sheb R	Kiwanis Pk	09/25/85	2.80	6.16	58.5	23.03	17.00	3.70

Table 3-14

1985 Lake Michigan Salmonid Data

Northern Zone
Chinook Salmon

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 1303	07/06/85	0.50	1.10	37.0	14.57	1.40		0.33
LK MICH	GRID 1303	07/06/85	0.50	1.10	38.0	14.96	0.80		0.24
LK MICH	GRID 1303	07/30/85	0.59	1.30	38.8	15.28	1.40		0.41
LK MICH	GRID 1303	08/05/85	0.59	1.30	39.8	15.67	1.50		0.23
LK MICH	GRID 1303	07/05/85	0.60	1.32	40.0	15.75	1.50		0.21
LK MICH	GRID 1303	07/30/85	0.68	1.50	40.0	15.75	0.90		0.22
LK MICH	GRID 1303	07/06/85	0.64	1.41	40.5	15.94	0.80	<QUANT.	0.10
LK MICH	GRID 1303	07/30/85	0.79	1.74	42.6	16.77	4.60		0.78
LK MICH	GRID 1303	07/30/85	0.74	1.63	43.9	17.28	1.30		0.25
LK MICH	GRID 506	07/12/85	0.75	1.65	44.0	17.32	1.50		0.41
LK MICH	GRID 1303	07/30/85	0.90	1.98	45.2	17.80	2.80		0.47
LK MICH	GRID 1303	07/30/85	0.99	2.18	45.9	18.07	6.00		0.88
LK MICH	GRID 1303	07/30/85	0.95	2.09	46.1	18.15	2.80		0.41
LK MICH	GRID 1303	07/30/85	0.96	2.11	46.3	18.23	3.10		0.54
LK MICH	GRID 1303	07/30/85	1.14	2.51	47.3	18.62	4.50		0.88
LK MICH	GRID 1303	07/30/85	1.11	2.44	48.1	18.94	5.00		0.73
LK MICH	GRID 1303	07/30/85	1.11	2.44	48.3	19.02	3.60		0.58
LK MICH	GRID 1303	07/30/85	1.12	2.46	48.6	19.13	3.00		0.46
LK MICH	GRID 1303	07/06/85	0.85	1.87	48.8	19.23	0.60	<QUANT.	0.10
LK MICH	GRID 1303	07/06/85	1.25	2.75	49.0	19.29	3.00		0.43
LK MICH	GRID 1303	07/06/85	1.15	2.53	49.5	19.49	0.90	<QUANT.	0.10
STURGN BAY	STRWBRRY CR	10/03/85	1.50	3.30	50.5	19.88	3.20		0.72
STURGN BAY	STRWBRRY CR	10/03/85	1.70	3.74	54.5	21.46	4.30		1.20
STURGN BAY	STRWBRRY CR	10/03/85	1.70	3.74	55.0	21.65	3.90		1.20
STURGN BAY	STRWBRRY CR	10/03/85	2.00	4.40	56.0	22.05	3.30		1.60
STURGN BAY	STRWBRRY CR	10/03/85	2.00	4.40	56.6	22.28	2.80		1.60
STURGN BAY	STRWBRRY CR	10/03/85	2.00	4.40	56.6	22.28	5.90		2.90
STURGN BAY	STRWBRRY CR	10/03/85	2.00	4.40	57.2	22.52	4.90		1.70
STURGN BAY	STRWBRRY CR	10/03/85	1.95	4.29	57.6	22.68	4.30		1.30
STURGN BAY	STRWBRRY CR	10/03/85	2.00	4.40	57.9	22.80	4.60		2.00
LK MICH	GRID 1303	07/06/85	2.00	4.40	59.2	23.31	6.30		1.30
STURGN BAY	STRWBRRY CR	10/03/85	2.50	5.50	61.0	24.01	6.40		2.30
LK MICH	GRID 905	06/11/85	2.30	5.06	61.0	24.02	9.40		0.86
LK MICH	GRID 1303	07/06/85	2.05	4.51	61.5	24.21	5.50		1.10
LK MICH	GRID 1303	07/06/85	2.10	4.62	62.0	24.41	5.50		0.88
STURGN BAY	STRWBRRY CR	10/03/85	2.50	5.50	62.2	24.49	3.30		2.50
LK MICH	GRID 1303	06/19/85	3.50	7.70	69.5	27.36	11.00		1.90
LK MICH	GRID 1303	07/06/85	3.10	6.82	70.5	27.76	10.00		1.50
STURGN BAY	STRWBRRY CR	10/03/85	3.30	7.26	71.5	28.15	1.90		1.50
LK MICH	GRID 805	07/05/85	4.60	10.12	71.8	28.27	11.00		1.90
LK MICH	GRID 1303	06/19/85	4.20	9.24	73.0	28.74	9.00		1.70
STURGN BAY	STRWBRRY CR	10/03/85	3.50	7.70	75.5	29.72	3.40		1.30
LK MICH	GRID 1303	05/22/85	4.95	10.89	77.5	30.50	9.40		1.40
LK MICH	GRID 1302	06/07/85	4.95	10.89	77.5	30.51	7.50		1.80
STURGN BAY	STRWBRRY CR	10/03/85	4.20	9.24	78.0	10.71	1.70		1.60
STURGN BAY	STRWBRRY CR	10/03/85	3.80	8.36	78.2	30.79	1.50		1.50
LK MICH	BAILEYS HAR	06/29/85	6.10	13.42	81.5	32.09	7.20		2.10
LK MICH	GRID 1303	06/19/85	7.10	15.62	84.5	33.27	9.00		2.00
LK MICH	WHITEFSH PT	07/05/85	6.55	14.41	84.7	33.35	8.90		3.10

Table 3-14 (continued)

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 1303	06/07/85	6.70	14.74	85.0	33.46	13.00		3.20
LK MICH	GRID 1303	07/06/85	6.10	13.42	85.0	33.46	6.50		1.60
LK MICH	GRID 1303	07/06/85	7.35	16.17	85.0	33.46	9.00		2.20
LK MICH	GRID 1303	07/06/85	5.95	13.09	85.5	33.66	5.90		1.10
LK MICH	GRID 805	06/29/85	7.40	16.28	87.0	34.25	10.00		2.50
LK MICH	GRID 1303	06/19/85	8.65	19.03	91.5	36.02	11.00		4.00
LK MICH	GRID 1303	07/06/85	7.70	16.94	91.5	36.02	9.00		2.70
LK MICH	GRID 805	06/29/85	8.00	17.60	92.1	36.25	7.90		2.50
LK MICH	GRID 806	07/19/85	9.70	20.24	92.5	36.42	8.90		2.70
LK MICH	GRID 1303	07/20/85	8.45	18.59	93.5	36.81	9.40		2.20
LK MICH	STURGN BAY	07/20/85	10.50	23.10	96.5	37.99	11.00		3.50
STURGN BAY	SHIP CANAL	08/28/85	.	.	100.5	39.57	6.10		5.50

Table 3-15

1985 Lake Michigan Salmonid Data

Southern Zone
Chinook Salmon

WATERBODY	LOCATION	DATE	WT_KILO	WT_LB	LNGTH_CM	LNGTH_IN	PCT_FAT	LIMIT	PCB
LK MICH	GRID 2102	06/21/85	0.33	0.73	32.0	12.60	13.00		0.42
LK MICH	GRID 2102	06/21/85	.	.	35.5	13.98	1.80		0.33
LK MICH	GRID 2102	06/21/85	.	.	36.0	14.17	1.80		0.44
LK MICH	GRID 2102	06/21/85	0.58	1.23	36.0	14.17	0.90		0.38
LK MICH	GRID 2102	06/21/85	0.43	0.95	36.0	14.17	0.70		0.38
LK MICH	GRID 2102	06/21/85	0.44	0.97	36.5	14.37	0.70	<QUANT.	0.10
LK MICH	GRID 1502	07/17/85	0.40	0.88	36.5	14.37	1.00		0.25
LK MICH	GRID 2102	06/21/85	0.60	1.32	37.0	14.57	1.00		0.28
LK MICH	GRID 1502	07/17/85	0.40	0.88	37.0	14.57	1.20		0.30
LK MICH	GRID 1502	07/17/85	0.45	0.99	38.0	14.96	0.90	<QUANT.	0.10
LK MICH	GRID 1502	07/17/85	0.40	0.88	38.0	14.96	0.50		0.37
LK MICH	GRID 2102	06/21/85	0.55	1.21	38.5	15.16	1.10		0.53
LK MICH	GRID 2102	06/21/85	0.53	1.17	39.0	15.35	1.00		0.52
LK MICH	GRID 2102	06/21/85	.	.	39.0	15.35	1.40		0.36
LK MICH	GRID 1502	07/17/85	0.50	1.10	39.0	15.35	0.80	<QUANT.	0.10
LK MICH	GRID 1502	07/17/85	0.55	1.21	39.0	15.35	2.00		0.47
LK MICH	GRID 1502	08/10/85	0.70	1.54	40.0	15.7	1.70		0.31
LK MICH	GRID 1502	07/17/85	0.65	1.43	40.5	15.9	4.00		0.47
LK MICH	GRID 1502	07/17/85	0.55	1.21	40.5	15.9	1.10		0.26
SHEB R	KIWANIS PK	09/25/85	0.75	1.65	41.0	16.14	9.10		2.70
LK MICH	GRID 1502	08/10/85	0.65	1.43	41.0	16.14	0.93	<QUANT.	0.10
LK MICH	GRID 1502	08/10/85	0.65	1.43	41.0	16.14	0.68	<QUANT.	0.10
LK MICH	GRID 1502	07/17/85	0.60	1.32	42.0	16.54	1.20		0.26
LK MICH	GRID 1502	08/10/85	0.75	1.65	42.0	16.54	1.60		0.32
LK MICH	GRID 1502	08/10/85	0.80	1.76	42.0	16.54	1.40		0.29
LK MICH	GRID 1502	08/10/85	0.80	1.76	43.0	16.93	1.60		0.32
LK MICH	GRID 1502	08/10/85	0.85	1.87	43.0	16.93	2.10		0.79
LK MICH	GRID 1502	07/17/85	0.70	1.54	43.5	17.12	0.80		0.34
LK MICH	GRID 1502	08/10/85	0.80	1.76	43.5	17.12	3.80		0.54
LK MICH	GRID 1502	08/10/85	0.80	1.76	43.5	17.12	1.50		0.44
LK MICH	GRID 1502	08/10/85	0.80	1.76	44.0	17.32	2.10		0.44
LK MICH	GRID 1503	08/10/85	0.80	1.76	44.0	17.32	1.00		0.28
LK MICH	GRID 1502	08/10/85	0.90	1.98	44.5	17.52	2.50		0.23
LK MICH	GRID 1502	08/10/85	0.90	1.98	44.5	17.52	2.40		0.66
LK MICH	GRID 1502	08/10/85	0.80	1.76	44.5	17.52	2.00		0.55
LK MICH	GRID 1502	08/10/85	0.85	1.87	44.5	17.52	1.10		0.20
LK MICH	GRID 1502	08/10/85	0.85	1.87	44.5	17.52	2.00		0.39
LK MICH	GRID 1502	08/10/85	0.80	1.76	44.5	17.52	2.60		0.67
LK MICH	GRID 1502	08/10/85	0.85	1.87	44.5	17.52	1.60		0.29
LK MICH	GRID 1502	08/10/85	0.90	1.98	44.5	17.52	4.40		0.75
LK MICH	GRID 1502	07/17/85	0.75	1.65	45.0	17.72	0.90		0.30
LK MICH	GRID 1502	08/10/85	0.75	1.65	45.0	17.72	2.60		0.65
LK MICH	GRID 1502	07/15/85	0.90	1.98	46.0	18.11	0.85		0.71
LK MICH	GRID 1502	08/10/85	0.95	2.09	46.0	18.11	0.79		0.23
LK MICH	GRID 1502	08/10/85	0.95	2.09	46.0	18.11	1.60		0.30
LK MICH	GRID 1502	08/10/85	0.90	1.98	46.0	18.11	1.40		0.28
LK MICH	GRID 1502	08/10/85	1.05	2.31	46.5	18.31	4.80		0.93
LK MICH	GRID 1502	08/10/85	9.50	20.90	47.0	18.50	2.10		0.34
LK MICH	GRID 1502	07/15/85	0.90	1.98	47.5	18.70	0.70		0.30

Table 3-15(continued)

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 1502	08/10/85	1.05	2.31	47.5	18.70	1.20		0.28
LK MICH	GRID 1502	08/10/85	1.20	2.64	49.0	19.29	3.00		0.60
LK MICH	GRID 1502	08/10/85	1.15	2.53	49.0	19.29	2.80		1.10
LK MICH	GRID 2102	09/07/85	1.40	3.08	50.5	19.88	4.00		0.91
LK MICH	GRID 1502	07/17/85	1.05	2.31	50.5	19.88	1.00		0.20
ROOT R	SIXTH ST	09/19/85	.	.	50.8	20.00	3.00		0.90
SHEB R	KIWANIS PK	09/25/85	.	.	51.2	20.16	6.00		1.30
LK MICH	GRID 2102	09/07/85	1.50	3.30	52.0	20.47	2.70		0.49
LK MICH	GRID 1502	08/10/85	1.40	3.08	52.0	20.47	3.60		0.65
LK MICH	GRID 1502	08/10/85	1.25	2.75	53.0	20.87	0.70		0.28
LK MICH	GRID 1502	08/10/85	1.65	3.63	53.5	21.06	4.40		1.10
LK MICH	GRID 1502	08/10/85	1.55	3.41	54.5	2 .46	1.80		0.51
LK MICH	GRID 2102	09/07/85	1.85	4.07	55.0	21.65	2.60		0.45
SHEB R	KIWANIS PK	09/25/85	2.50	5.50	57.8	22.75	5.00		2.60
LK MICH	GRID 1502	08/10/85	2.00	4.40	59.5	23.42	3.90		1.10
SHEB R	KIWANIS PK	09/25/85	2.75	6.05	61.7	24.28	8.00		3.10
LK MICH	GRID 2102	06/01/85	2.22	4.88	62.5	24.60	9.00		1.10
LK MICH	GRID 1502	08/10/85	2.35	5.17	62.5	2 .60	0.78		0.26
LK MICH	GRID 1502	07/15/85	3.10	6.82	63.0	2 .80	8.80		2.60
LK MICH	GRID 2102	06/01/85	2.16	4.75	63.5	25.00	8.20		1.20
LK MICH	GRID 1502	08/10/85	2.40	5.28	65.0	25.59	0.82		0.31
LK MICH	GRID 2102	06/01/85	2.19	4.82	65.0	25.60	5.50		0.91
SHEB R	KIWANIS PK	09/25/85	3.00	6.60	67.3	26.50	3.90		2.00
LK MICH	GRID 2102	09/07/85	2.90	6.38	67.4	26.54	4.30		0.92
SHEB R	KIWANIS PK	09/25/85	3.80	8.36	67.5	26.57	3.30		1.20
SHEB R	KIWANIS PK	09/25/85	.	.	68.6	27.00	2.50		2.10
LK MICH	GRID 1502	08/10/85	3.05	6.71	69.5	27.36	4.40		0.99
LK MICH	GRID 2202	07/20/85	2.90	6.38	70.0	27.56	0.80		0.35
LK MICH	GRID 2102	06/01/85	3.01	6.62	70.6	27.80	6.20		0.80
SHEB R	KIWANIS PK	09/25/85	3.50	7.70	70.9	27.90	1.30		1.20
LK MICH	GRID 2102	06/01/85	4.00	8.80	71.1	28.00	16.00		0.90
SHEB R	KIWANIS PK	09/25/85	3.70	8.14	71.8	28.25	1.80		2.60
LK MICH	GRID 1502	08/10/85	3.55	7.81	72.0	28.35	5.70		1.30
LK MICH	GRID 2102	06/01/85	3.46	7.61	72.4	28.50	7.60		2.00
LK MICH	GRID 1502	08/10/85	3.00	6.60	72.5	28.54	1.70		0.63
LK MICH	GRID 1502	08/10/85	4.10	9.02	74.0	29.13	1.90		1.20
LK MICH	GRID 1502	08/10/85	3.10	6.82	74.0	29.13	2.60		1.10
LK MICH	GRID 1502	06/29/85	3.75	8.25	74.5	29.33	7.10		1.50
LK MICH	GRID 1502	08/10/85	3.90	8.58	75.0	29.53	5.20		1.60
LK MICH	GRID 1502	08/10/85	3.95	8.69	75.5	29.72	10.50		1.30
SHEB R	KIWANIS PK	09/25/85	3.95	8.69	75.6	2 .75	2.30		1.40
LK MICH	GRID 1502	08/10/85	4.70	10.34	76.0	2 .92	4.30		1.00
LK MICH	GRID 1901	06/29/85	5.20	11.44	77.0	30.31	9.80		2.50
LK MICH	GRID 1502	08/10/85	4.25	9.35	78.0	30.71	5.90		1.30
LK MICH	GRID 2102	06/01/85	4.66	10.25	79.0	31.10	5.60		1.70
SHEB R	KIWANIS PK	09/25/85		.	79.2	31.18	2.60		1.80
LK MICH	GRID 1502	08/10/85	6.00	13.20	79.5	31.30	3.80		2.00
LK MICH	GRID 2102	07/20/85	4.10	9.02	80.0	31.50	0.50		0.57
SHEB R	KIWANIS PK	09/25/85	6.85	15.07	81.8	32.20	4.70		2.80

Table 3-15 (continued)

WATERBODY	LOCATION	DATE	WT KILO	WT LB	LNGTH CM	LNGTH IN	PCT FAT	LIMIT	PCB
LK MICH	GRID 1502	08/10/85	3.50	7.70	82.0	32.28	1.10		1.30
SHEB R	KIWANIS PK	09/25/85	.	.	82.2	32.36	2.30		2.40
SHEB R	KIWANIS PK	09/25/85	.	.	82.5	32.48	3.10		2.30
LK MICH	GRID 1502	08/10/85	5.60	12.32	82.5	32.48	4.40		2.20
LK MICH	GRID 1502	08/10/85	6.45	14.19	83.0	32.68	5.10		1.40
LK MICH	GRID 2102	07/20/85	5.80	12.76	84.0	33.07	9.30		2.80
SHEB R	KIWANIS PK	09/25/85	.	.	84.7	33.35	2.40		2.10
LK MICH	GRID 2102	06/01/85	6.40	14.08	85.1	33.50	7.50		2.10
SHEB R	KIWANIS PK	09/25/85	.	.	85.5	33.66	2.60		2.80
LK MICH	GRID 1901	06/25/85	6.05	13.31	86.4	34.00	9.00		3.90
LK MICH	GRID 1502	08/10/85	5.80	12.76	87.0	34.25	4.50		2.30
LK MICH	GRID 1502	08/10/85	6.30	13.86	87.5	34.45	4.80		2.60
LK MICH	GRID 2102	09/07/85	7.25	15.95	87.8	34.57	3.00		1.20
LK MICH	GRID 2102	09/07/85	7.75	17.05	88.2	34.72	1.50		1.20
LK MICH	GRID 2102	09/07/85	5.95	13.09	88.6	34.87	1.50		0.80
LK MICH	GRID 2102	06/01/85	5.23	11.51	89.4	35.20	3.00		1.90
LK MICH	GRID 1502	07/15/85	8.10	17.82	89.5	35.24	4.60		2.40
SHEB R	KIWANIS PK	09/25/85	.	.	89.8	35.35	2.80		3.80
SHEB R	KIWANIS PK	09/25/85	.	.	91.0	35.83	5.30		2.40
LK MICH	GRID 2102	07/20/85	7.60	16.72	93.5	36.81	6.20		2.70
SHEB R	KIWANIS PK	09/25/85	.	.	95.3	37.52	3.00		4.00
LK MICH	GRID 2002	06/21/85	10.32	22.70	98.5	38.00	11.00		2.40

Table 3-16

PCB Concentrations by Species by Location

Fish	Region	# Samples	Mean PCB
Brook Trout	Main Basin	24	0.82
	Northern	17	0.74
	Southern	7	1.01
	Sheboygan River	18	1.84
	TOTAL	42	1.26
Rainbow Trout	Main Basin	34	0.65
	Northern	14	0.72
	Southern	20	0.61
	Sheboygan River	12	2.34
	TOTAL	46	1.09
Lake Trout	Main Basin	147	3.64
	Northern	65	3.16
	Southern	82	4.03
Brown Trout	Main Basin	85	2.01
	Northern	43	1.94
	Southern	42	2.09
	Sheboygan River	13	2.48
	TOTAL	98	2.07
Coho Salmon	Main Basin	68	0.87
	Northern	10	0.83
	Southern	58	0.88
Chinook Salmon	Main Basin	181	1.22
	Northern	61	1.45
	Southern	120	1.10

Table 3-17

PCB Concentrations by Species in Lake Michigan

Fish	Region	# Samples	Mean PCB
Lake Trout	Illinois[a]	6	0.54
	Indiana	20	11.16
	Michigan	54	1.53
	Wisconsin[b]	147	3.64
		227	3.72
Brown Trout	Illinois[a]	17	0.66
	Indiana	17	3.35
	Michigan	--	--
	Wisconsin	24	2.64
	Wisconsin[b]	98	2.07
	TOTAL	153	2.12
Brook Trout	Wisconsin	42	1.26
Rainbow Trout	Illinois[a]	8	0.26
	Indiana	15	0.88
	Wisconsin	4	0.69
	Wisconsin[b]	46	1.09
	TOTAL	73	0.93
Chinook Salmon	Illinois[a]	27	0.87
	Indiana	55	2.20
	Michigan	26	0.78
	Wisconsin	26	2.18
	Wisconsin[b]	120	1.10
	TOTAL	254	1.39
Coho Salmon	Illinois[a]	7	0.39
	Indiana	44	0.85
	Michigan	20	1.07
	Wisconsin	25	0.68
	Wisconsin[b]	68	0.87
		164	0.84

[a]Based on data from 1984-1985.
[b]Based on data from 1985.

Table 3-18

Average PCB Concentrations for Trout and Salmon by State

State	PCB Trout (# fish)	PCB Salmon (# fish)
Illinois	0.53 (31)	0.78 (34)
Indiana	5.76 (49)	1.60 (99)
Michigan	1.53 (54)	0.79 (70)
Wisconsin	2.51 (361)	1.11 (239)
	495 fish	442 fish
Average of all states	2.60 (0.13-20.0)	1.14 (0.02-5.04)

Tab'e 3-19

Angler Days, Fishermen and Total Number
of Trout and Salmon Caught in Lake Michigan

State	Fishermen	Angler Days	Trout	Salmon
Michigan	349,000	2,637,000	529,000	1,177,000
Wisconsin	240,000	944,000	182,300	493,000
Illinois	634,000	3,569,000	596,000	1,075,000
Indiana	34,000	184,000	40,000	59,000
TOTAL	1,257,000	7,334,000	1,347,000	2,804,000

Table 3-20

Fish Length Required to Reach the
FDA Limit of 2 ppm PCB Concentration

Fish Species	Size to exceed 2 ppm (inches)	p-value
Brook Trout	15.2	0.0032
Rainbow Trout	all below 2 ppm	N.S.
Lake Trout	22.8	0.0001
Brown Trout	20.9	0.0017
Coho Salmon	all below 2 ppm	0.0001
Chinook Salmon		
Northern zone	29.5	0.0001
Southern	32.9	0.0001

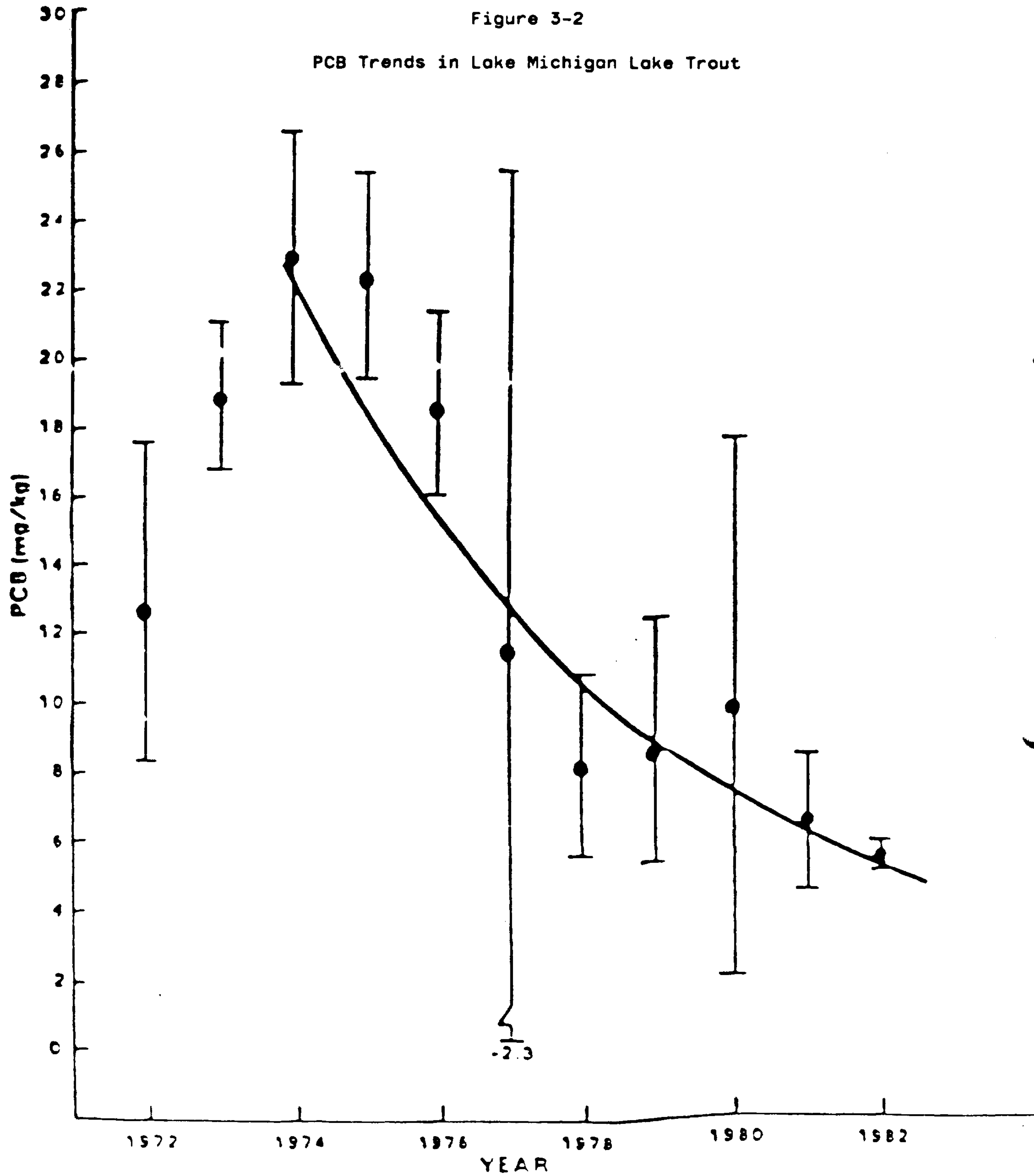
Figure 3-1

Fish Inventory for Lake Michigan

Alewife	Lake Trout
Black Bullhead	Lake Whitefish
Black Crappie	Largemouth Bass
Bloater	Least Darter
Bluegill	Longnose Dace
Bluntnose Minnow	Longnose Sucker
Brook Stickleback	Mottled Sculpin
Brook Trout	Ninespine Stickleback
Brown Trout	Northern Pike
Burbot	Pumpkinseed
Carp	Rainbow Smelt
Central [illegible]innow	Rainbow Trout
Chinook Salmon	Rock Bass
Cisco	Sand Shiner
Coho Salmon	Sea Lamprey
Common Shiner	Slimy Sculpin
Emerald Shiner	Spottail Shiner
Fathead Minnow	Stizostedion Vitreum
Fourhorn Sculpin	Tadpole Madtom
Gizzard Shad	Trout - Perch
Golden Shiner	Warmouth
Goldfish	White Crappie
Johnny Darter	White Sucker
Lake Chub	Yellow Bullhead
Lake Sturgeon	Yellow Perch

Figure 3-2

PCB Trends in Lake Michigan Lake Trout



4. Remedial Action Alternatives

4.1. Site Description

4.1.1. Waukegan Harbor

Waukegan Harbor is an irregularly shaped harbor of approximately 170,000 square meters. The sediments are characterized by a soft organic silt (muck) ranging from 0.3 to 1.8 meters deep, overlying a layer of coarse sand atop a thick layer of stiff glacial till (clay). Water depths in the harbor range from approximately 2 meters in the shallowest portion of Slip #3 to 7 meters in the outer harbor. The entire harbor, with the exception of the boat launching areas of the Waukegan Port District, is surrounded by 6 to 8 meters of long steel sheet piling which generally extends into the sand layer above the glacial till.

For purposes of this study, based on PCB levels in the sediments and water, the harbor is subdivided into four areas: Slip #3, the upper harbor, the lower harbor and the outer harbor. These areas are depicted in Figure 1-1. Slip #3 and the upper harbor are the major areas of concern in Waukegan Harbor since these areas contain the highest levels of PCBs in both sediment and water.

4.1.2. North Ditch

The North Ditch is a drainage ditch covering approximately 4,300 square meters and is located near the northern boundary of the OMC property. The North Ditch is comprised of three areas including: the

Crescent Ditch, Oval Lagoon and the East-West Channel (referred to as the E-W channel), ultimately discharging into Lake Michigan (Figure 1-1). The sediments of the North Ditch are composed of a layer of debris, black grit and fine overlying sand and gravel. The hydraulic characteristics (depth and flow rate) of the North Ditch are influenced by Lake Michigan. As the water level in Lake Michigan changes with the wind direction, the depth and flow of water in the North Ditch respond. As a result, the direction of flow is occasionally reversed. The North Ditch, in turn, is an influential factor in the flow of groundwater in the area. Depending on the water level in the ditch, it can serve as either a discharge or recharge boundary for the groundwater.

4.1.3. Parking Lot

The parking lot is a land area of approximately 36,000 square meters just south of the North Ditch. Presently this area is predominantly covered by asphalt to accommodate the parking needs of OMC. The underlying soils have been found to contain elevated concentrations of PCBs.

4.2. PCB Distribution

4.2.1. Sediment and Soils

Waukegan Harbor: Waukegan Harbor sediments have been found to contain elevated concentrations of PCBs. Presently there are no active discharges to the harbor; the sediments comprise the major source of PCBs to the water column. The most highly contaminated sediments found in the harbor are concentrated near the western end of Slip #3.

Concentrations of up to 500,000 ppm PCBs were found in some samples taken from this region. The sediment samples reflected decreasing levels with distance from the western end of Slip #3. Near the mouth of the harbor, PCB concentrations in the surficial muck are less than 10 ppm. Figure 4-1 presents the average PCB concentrations of the muck in Waukegan Harbor as reported in the engineering study conducted by Mason & Hanger-Silas Mason Co., Inc. (1981).

Although Slip #3 comprises less than 3% of the total area of Waukegan Harbor, it is estimated that 98% of the total mass of PCBs in the harbor are contained in the sediments of this area. Slip #3 is the only area of the harbor where PCBs have been detected in the sand and clay layers beneath the surficial muck. In some locations, small pools of PCBs have formed on top of the clay layer due to the impermeable nature of the clay. These pools are believed to be confined to a small area in the northwest corner of Slip #3.

Elevated levels of PCBs were also observed in the soils in the northwest corner of Slip #3, behind the steel sheet piling which lines the harbor. It has been suggested that the PCBs found in this soil originated from two processes: 1) use of dredged material as backfill, and 2) seepage of PCBs behind the sheet piling from the pools on top of the clay layer in Slip #3.

North Ditch Area: The sediments in the Crescent Ditch and Oval Lagoon have elevated levels of PCBs. Both areas contain pockets of soil with PCB concentrations over 50,000 ppm. The location of these pockets is depicted in Figure 4-2. The sediments of the E-W Channel have lower concentrations of PCBs than the Crescent Ditch and Oval

Lagoon with an estimated average sediment PCB concentration of approximately 200 ppm. In the E-W Channel, sediment PCB concentrations decrease with distance from the Oval Lagoon. Figure 4-2 presents the average PCB concentrations found in the North Ditch area sediments and surrounding soils. Certain locations in the soils surrounding the Crescent Ditch and Oval Lagoon also contain elevated levels of PCBs.

Parking Lot Area and Groundwater: The general soil profile in the parking lot area is characterized by a layer of fill and two distinct layers of sand overlying a silt layer containing pockets of gravel. In a groundwater study completed in 1981 by JRB Associates, two groundwater and soil "hotspots" were identified. One in the Crescent Ditch/Oval Lagoon vicinity; the second is located south of the E-W Channel near the east end. The soil "hotspots" are diagrammed in Figure 4-2.

In the groundwater, PCB concentrations were reported to exceed 10,000 ppb in both areas, and concentrations up to 100,000 ppm have been found in the soil. Since the values reported for the groundwater samples significantly exceed the solubility of PCBs (approximately 0.2 ppm) these samples may have been appreciably contaminated with surrounding soils or may reflect the presence of a co-solvent. Four groundwater flow patterns were identified by JRB Associates during 12 nonconsecutive days of observations. Under the majority of flow conditions, groundwater is believed to discharge directly into the North Ditch. Groundwater flows into Lake Michigan under two types of flow that occurred on 4 of the 12 observation days. Presently, Lake Michigan is not believed to be receiving a significant PCB load from the groundwater in the North Ditch area. However, JRB projections (JRB Associates, 1981) indicate that in approximately 60 years the parking lot area may become a source of PCBs to Lake Michigan through groundwater migration.

4.2.2. Water

Waukegan Harbor: Many factors influence PCB concentrations in the water column, but the major source of PCBs to Waukegan Harbor water is the underlying sediment. Therefore, the general trend of water column PCB distribution reflects that of the sediments. PCB concentrations in the water are greatest in Slip #3 and decrease with distance from the slip. Although the water column has not been as extensively analyzed as the sediments, some data do exist. Reported or estimated values representing average PCB concentrations in the water in the late 1970s, are presented in Table 4-1. PCB data for water have been collected at two locations in the harbor over the past nine years and is presented in Figure 4-3. The samples are collected and analyzed monthly as part of the monitoring requirements of OMC's NPDES permit. The sampling stations are located at two cooling water intake pipes; one located in Slip #3 (HI-2); the other in the upper harbor across from Slip #1 (HI-1).

North Ditch: PCB concentrations in the water of the North Ditch are principally influenced by PCB concentrations in the underlying sediments. Additionally, the North Ditch serves primarily as a discharge boundary to the fill-sand aquifer described above. Groundwater flows to the North Ditch under the majority of groundwater flow patterns and may transport PCBs. Therefore, the groundwater is potentially a second source of PCBs to the North Ditch water.

Characterization of the PCB concentrations in the North Ditch water column is difficult due to the paucity of data. However, the water of the Crescent Ditch has been estimated to have an historic average PCB concentration of 7.0 $\mu g/\ell$ (Thomann and Kontaxis, 1981). A rough estimation of the average concentrations for the other areas of the North Ditch may be made by considering the relative concentrations per area during a storm event as modeled by Thomann and Kontaxis (1981) and with the assumption that the concentration ratios remain constant under average ambient conditions. Approximate PCB concentrations in the North Ditch are given in Table 4-1.

4.3. Record of Decision Alternative (ROD)

Since the discovery of PCBs on the OMC site, many studies have been undertaken to determine the distribution of PCBs, export of PCBs from the site and the potential impact of PCBs originating from this site on aquatic and human life. Utilizing the information gathered from this site, including site specific PCB transport modeling completed by Thomann and Kontaxis (1981), and knowledge of PCBs in general, the U.S. EPA stated that remedial actions in Waukegan Harbor, the North Ditch and parking lot areas of the OMC property are necessary. Further, cleanup of contaminated areas containing greater than 50 ppm PCBs was deemed appropriate.

Based upon the Toxic Substances Control Act (TSCA) and the National Contingency Plan, the EPA at first selected a cost-effective clean-up plan which the agency believed was consistent with other environmental laws and applicable to the site. The total cost of this remedy was estimated to be nearly $75 million (USEPA, 1984). Since the EPA must be able to act on a number of sites which may pose threats to environmental and/or human health, the agency determined that the cost was inappropriately high and a fund-balanced approach was sought.

The EPA subsequently selected a fund-balanced remedial action plan which is put forth in the Record of Decision (ROD) (USEPA, 1984). According to the EPA, this plan does not meet all TSCA requirements and is deemed to be less protective than the cost-effective plan mentioned above. Nonetheless, the fund-balanced remedy is expected by EPA to be effective in preventing the migration of PCBs from the site which would threaten public health, welfare or the environment (USEPA, 1984). The fund-balanced action (ROD) is summarized in Table 4-2 and described in the paragraphs below.

The exact construction designs, and schedule for implementation of this remedial action alternative have not yet been completed. Many of these details are necessary to fully complete this risk assessment. In instances where the required details were not available, assumptions and estimates were made. These estimates and assumptions are indicated below.

4.3.1. Waukegan Harbor

Under the Record of Decision alternative, all sediments in Waukegan Harbor containing PCBs with concentrations greater than 50 ppm are designated for removal from the harbor and subsequently confined to prevent migration of PCBs into the environment. The sediments containing levels higher than 10,000 ppm will be removed and disposed of offsite in a licensed chemical landfill. Those harbor sediments containing less than 10,000 ppm PCBs will be dredged and ultimately confined in a containment cell to be constructed on the OMC parking lot. Roughly 300,000 cubic yards of sediment will be removed from the harbor under this alternative.

Hotspots: Hotspots are defined herein as those areas where PCB concentrations exceed 10,000 ppm. There is one hotspot in Waukegan Harbor, near the northwest corner of Slip #3. In this vicinity, elevated levels of PCBs have been found in the surficial muck, underlying sand and clay and the soil behind the steel sheet piling. All this material, roughly 5700 cubic yards, will be excavated and disposed of offsite in a licensed hazardous waste facility.

In order to proceed, a cofferdam will be constructed surrounding the sediments and soils at the western end of Slip #3. At this time the exact construction characteristics and placement of the cofferdam are uncertain but reflect a configuration suggested by Mason & Hanger-Silas Mason Co., Inc. (1981). Once the cofferdam is in place, the water will be pumped from the confined area, treated to remove the PCBs and subsequently returned to the harbor. The sediments will be fixed to help minimize volatilization, excavated and transported to the hazardous waste facility.

500-10,000 ppm PCB: An estimated 5000 cubic yards of sediment found in Slip #3 and the uppermost portion of the harbor contain PCB levels between 500 and 10,000 ppm. This material will be dredged, dewatered and disposed of onsite.

A silt screen will be placed across the upper harbor just above Slip #1 to minimize transport of sediment and particulate PCBs into the lower harbor. A hydraulic or pneumatic dredge will most likely be used to remove the surficial muck and deposit it into a dewatering lagoon (OMC-1) to be built on vacant OMC property. The sediments will be fixed to minimize volatilization during dewatering. It is not clear whether long term dewatering will occur or if pumping will be employed to minimize the time of environmental exposure to PCBs. Once dewatered, these sediments will be placed in a containment cell which is to be built on the OMC parking lot.

50-500 ppm PCB: Approximately 75% or 35,700 cubic yards of the harbor sediments slated for removal under the ROD alternative are estimated to contain between 50 and 500 ppm PCBs. These sediments are in the upper harbor and will be dredged, dewatered and disposed of onsite.

The silt screen will remain in place while the lower part of the upper harbor is dredged. The dredged material will be deposited in a second dewatering lagoon (OMC-2) to be built adjacent to OMC-1 on vacant OMC property. The sediments will be left to dewater over an approximate two year period before disposal in the containment cell to be built on the OMC parking lot.

4.3.2. Dewatering Lagoons

Under the ROD remedial action alternative two dewatering lagoons will be constructed on vacant OMC property located just east of the harbor and north of Outboard Marine Corporation Plant #1. This vacant property is identified on Figure 1-1. The dimensions of the lagoons are not given but are important for the estimation of volatilization rates and subsequent assessment of risk due to inhalation of PCBs. Therefore, estimates of the sizes of the dewatering lagoons have been made.

Mason & Hanger-Silas Mason Co., Inc. (1981) indicated that the water surface area of a proposed lagoon at Waukegan Harbor, when full, would be approximately 280,000 square feet (26,000 square meters). The sizes of the lagoons were estimated as proportional to the volume of dredge material to be deposited, under the assumption that the slurry in the two lagoons will have a combined surface area equal to that of the single, previously proposed lagoon and that the slurry in both lagoons will have equal depths. The lagoons, when full, will be about 13 feet high (4 meters) and the estimated surface areas of the slurry in dewatering lagoons OMC-1 and OMC-2 will be approximately 35,200 square feet (3,270 square meters) and 244,800 square feet (22,750 square meters), respectively.

4.3.3. Parking Lot

The soils beneath the pavement of the parking lot will not be removed. Instead, a containment cell will be built in the area for confinement of these soils and the dredged sediment from Waukegan Harbor and Slip #3. The sediment will be brought to the parking lot, graded, compacted and contained by slurry walls which will penetrate the soil down to the glacial till. Finally, the cell will be capped with an impermeable material and covered with pavement.

Although the size of the containment area was not reported in the Record of Decision, its height above ground is estimated to be 14 feet after completion. Disregarding the thickness of the cap and assuming that the dredged sediment from Waukegan Harbor and Slip #3 will be deposited at ground level, the containment cell will have an estimated area of 78,500 square feet (7,300 square meters) inside tha slurry walls.

4.3.4. North Ditch Area

The ROD remedial action alternative calls for confinement of all materials with PCB levels greater than 50 ppm. As in the harbor, hotspots (>10,000 ppm) found in the North Ditch area will be excavated and disposed of offsite in a licensed hazardous waste facility. The sediments and soils containing less than 10,000 ppm PCBs will be excavated and contained onsite. It is estimated that nearly 53,000 cubic yards of sediment and soil will be confined to minimize PCB migration into the environment.

Under the ROD alternative, a bypass drainage pipe will be constructed in the North Ditch to prevent further transport of PCBs from the North Ditch and surrounding soils into Lake Michigan. Any material excavated during this construction will be deposited in a containment cell to be built in the Crescent Ditch/Oval Lagoon area. The Crescent Ditch, Oval Lagoon and E-W Channel of the North Ditch will then be left to dewater in place by evaporation, or the water will be decanted, treated and returned to Lake Michigan. The Record of Decision does not indicate whether any of the sediments or soils will be fixed to minimize volatilization from the exposed area.

Prior to the construction of the containment cell, an estimated 5500 cubic yards of sediment and soil in and around the Crescent Ditch and Oval Lagoon must be removed. This material contains PCBs in excess of 10,000 ppm. Once excavated, this material will be transported offsite for disposal in a licensed hazardous waste facility.

The containment cell will be built in the area of the Crescent Ditch and Oval Lagoon. Slurry walls will be constructed down to the glacial till to minimize migration of PCBs. Sediments in the North Ditch area containing less than 10,000 ppm PCBs will be excavated and disposed of in this containment cell. When the excavation is completed, the cell will be covered with an impermeable cap.

Although the size of the containment cell is uncertain, an estimate can be made utilizing assumptions similar to those stated above. In this case, however, the height above ground must also be assumed. Fourteen feet was chosen as the height above ground for consistency. The area of the cell, inside the slurry walls, would then be approximately 92,000 square feet (8,550 square meters).

4.4. In-Place Containment Alternative (IPC)

In accordance with the EPA's decision that all sediments contaminated with PCB concentrations greater than 50 ppm be contained, the in-place containment (IPC) alternative will confine, onsite, all sediments in Waukegan Harbor and the North Ditch Area with PCB levels higher than 50 ppm. A summary of the IPC alternative is presented in Table 4-3.

4.4.1. Waukegan Harbor

Under the IPC alternative a containment cell would be built in the Slip #3 area of Waukegan Harbor. A sheet pile/sand wall and a slurry wall would be constructed across the mouth of the Slip. The cell will have an area of approximately 54,000 square feet (5,000 square meters). Figure 1-1 indicates the approximate location of the outer wall of the containment cell at the boundary of Slip #3. Once the slurry wall is completed, the sediments in Slip #3 will be essentially confined and isolated. Sediments from the upper harbor with PCB levels greater than 50 ppm will be dredged and deposited in the containment cell in Slip #3. These sediments will be dewatered in-situ by pumping the water to a local treatment facility once sedimentation has occurred. A high volume water treatment plant will be employed to remove PCBs from the water before returning it to the harbor.

4.4.2. North Ditch Area

The IPC alternative proposes construction of a storm drain to divert surface runoff and cooling water away from the North Ditch directly into Lake Michigan. The entire North Ditch will then be dewatered in place either via evaporation or by decanting. Once the sediments are dry, the Crescent Ditch, Oval Lagoon and E-W Channel will be filled, capped with clay and covered with topsoil and vegetation. The North Ditch is presently a major influential factor for groundwater flow in the area. Filling the Ditch will probably alter the groundwater flow patterns. Therefore, reasonable estimates of PCB transport after the Ditch is filled are precluded. Under the IPC alternative, a study will be conducted after the North Ditch has been filled to assess the need for further action to minimize, if necessary, the migration of PCBs through the groundwater.

4.4.3. Parking Lot

Although no immediate action is proposed specifically for the parking lot, the storm drain will be constructed through a portion of the parking lot. Any material excavated during the construction activities will be placed in the Crescent Ditch before filling and capping. The remainder of the soils in the parking lot will remain undisturbed. As in the North Ditch area, monitoring will be conducted and the need for the actions to minimize groundwater transport of PCBs will be assessed.

Table 4-1

[PCB] in Water Column

Location	Average [PCB] (ppb)
Waukegan Harbor	
Slip #3	0.51
Upper Harbor	0.39
Lower Harbor	0.26
Outer Harbor	0.15
North Ditch	7.00*
Crescent Ditch	8.05
Oval Lagoon	7.00
E-W Channel	5.08**

* Reported
** Estimated

Table 4-2

Record of Decision Alternative Summary

Location	Contamination Level	Volume Sediment (YD^3)	Removal Method	Treatment	Disposal
Slip #3 - near old OMC outfall	>10,000 ppm	5,700	excavate w/ cofferdam	fix, treat water	offsite
Slip #3 and Upper Harbor	500-10,000 ppm	5,000	dredge using silt screen	dewater- OMC 1, treat water fix sediments	Parking Lot capped containment cell
Upper Harbor	50-500 ppm	35,700	dredge using silt screen	dewater- OMC - 2, treat water cell	Parking Lot capped containment
Oval Lagoon and Crescent Ditch	>10,000 ppm	5,500	excavate		offsite
North Ditch	<10,000 ppm	47,300	excavate	dewater in place after installation of by-pass pipe	Oval Lagoon, Crescent Ditch area, capped containment cell
Parking Lot	all	105,000	none	graded, compacted	in-situ w/ slurry wall, imperm. cap and pavement

Table 4-3

IPC Alternative Summary

Location	Description
North Ditch	Construction of storm drain to divert surface runoff and cooling water away from North Ditch into lake directly. Any removed material is placed in Crescent Ditch. Fill in ditch, Crescent Ditch and Oval Lagoon, cap with clay and cover with topsoil and vegetation. Construction of monitoring wells.
Parking Lot	No action. Any material removed during excavation for storm drain will be placed in Crescent Ditch.
Slip #3 Upper Harbor	Slurry wall will be built between Slip #3 and upper harbor; upper harbor dredged to 50 ppm PCB slurry deposited behind slurry wall. Sediments dewatered, water treated, cell capped with clay. New slip for Larsen Marine

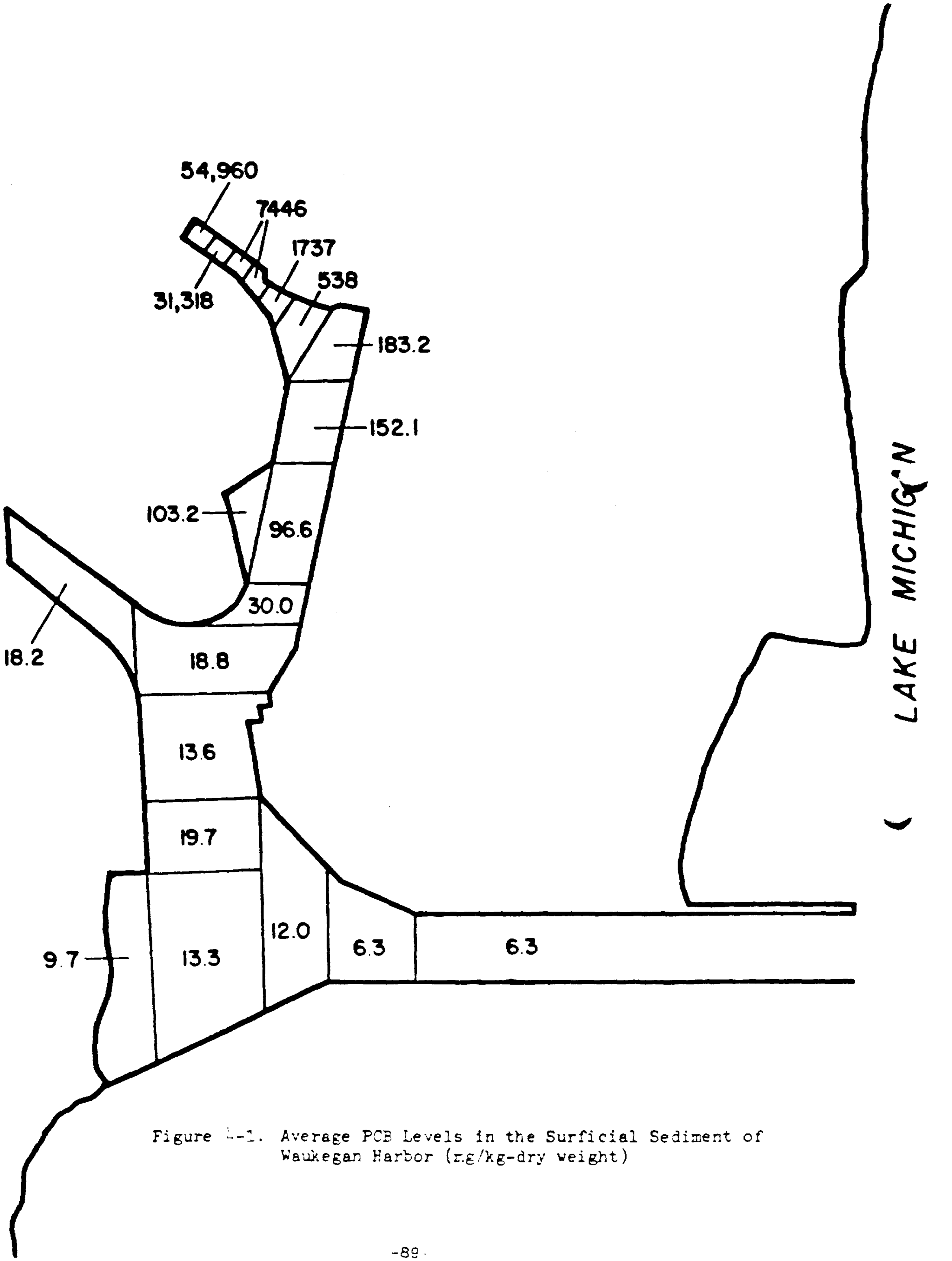
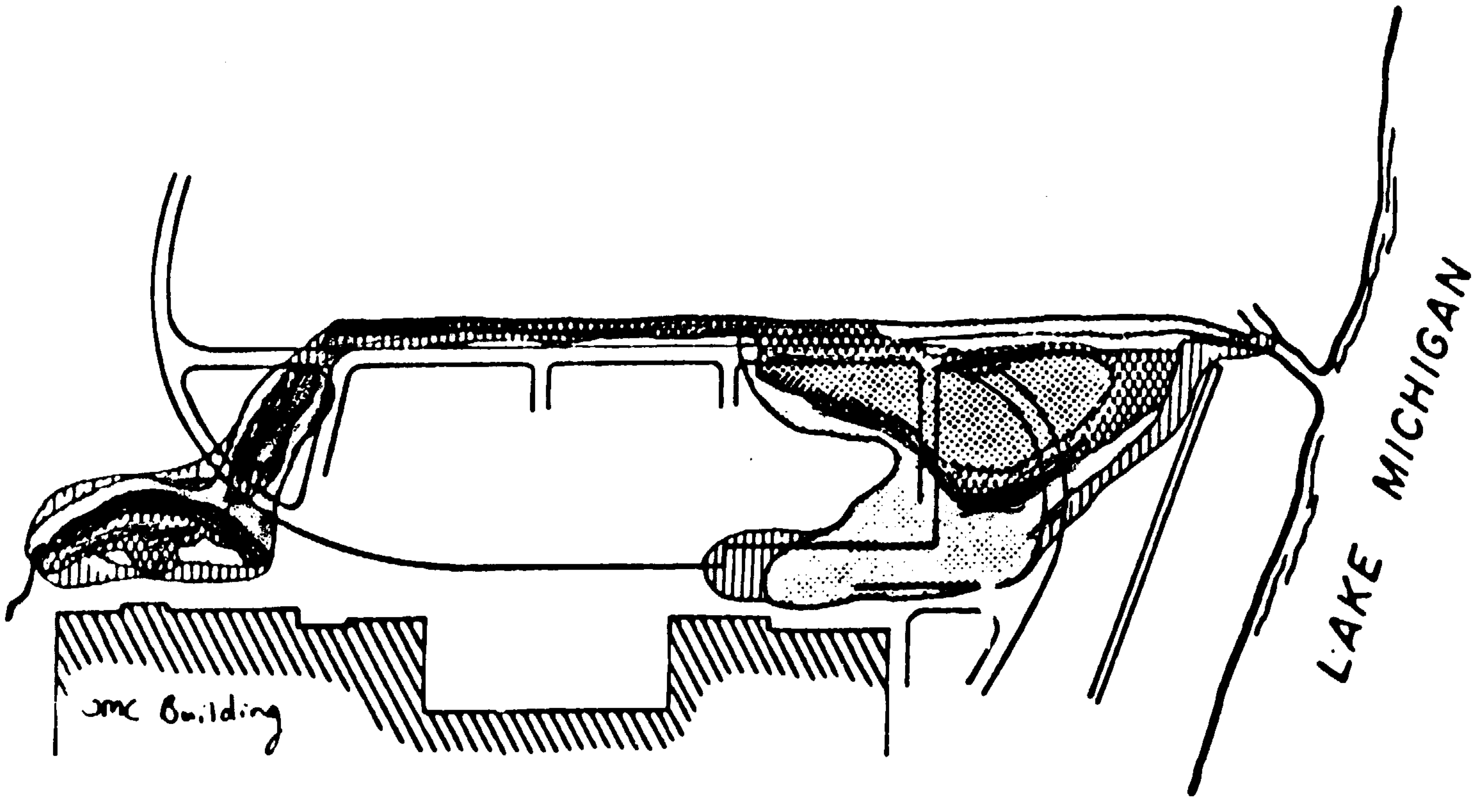


Figure 4-1. Average PCB Levels in the Surficial Sediment of Waukegan Harbor (mg/kg-dry weight)



Approximate Scale: 1cm = 40m

LEGEND

- >20 to 50 PPM PCB
- 51 to 500 PPM PCB
- 501 to 5000 PPM PCB
- >5000 PPM PCB

Figure 4-2. PCB Levels in the Soil and Sediment of the North Ditch

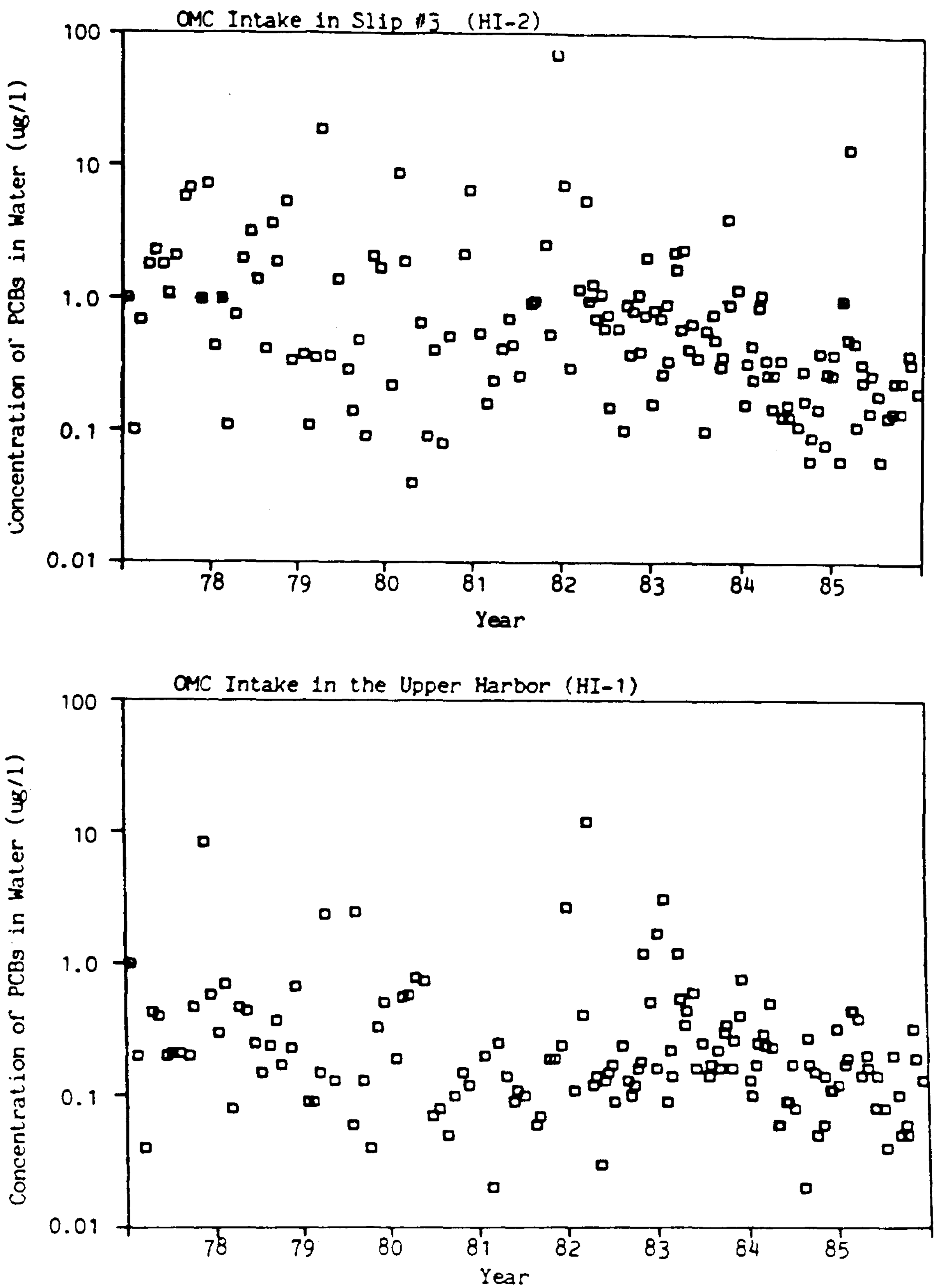


Figure 4-3

Monthly PCB Data in Water at Two Locations in Waukegan Harbor, 1977-1985

5. Source ana Fate Assessment

5.1. Background

Water quality assessment often requires integration of scientific information in an effort to not only understand present conditions, but to also make knowledgeable predictions about future water quality. A principal tool that the scientific and regulatory community uses to integrate various information is the water quality model. Water quality models can permit comprehensive site-specific contaminant assessments. Models of water resources have played a role in regulatory decision making for the last two decades. In fact, mathematical models are now a part of federal regulatory guidelines for predicting system response to various remedial alternatives (USEPA Water Quality Assessment, 1985; *Federal Register*, 1986).

Water quality models are designed to represent known processes which influence the fate of a chemical of interest in an aquatic system. In this study the fate of polychlorinated biphenyls (PCBs) in response to proposed remedial actions is of interest. The fate of PCBs is an important component in determining the degree of exposure which is information required by the risk assessment. Specifically, a PCB model can simulate and forecast the level (or concentration) of PCBs in environmental compartments. These compartments may include the water column, underlying sediments, and fish.

Several models of PCBs in Lake Michigan have been developed in recent years. Rodgers (1982) developed a PCB model to assist EPA and others in assessing the relative importance of various sources of PCBs to the observed levels in Lake Michigan. The model was used to predict the response of PCBs in water and sediment to selected loadings of PCBs to the lake. Rodgers and Swain (1983) further developed this model to permit a retrospective assessment of historical loads based on scientific inference from historical PCB levels in fish. This model enabled a forecast of expected compliance times to FDA consumption guidelines in Lake Michigan. Thomann and DiToro (1983) developed a toxic substances model for the Great Lakes in which they examined the fate of PCBs. The kinetics and the fate predictions of these models are quite similar. The only difference of note is that Thomann and DiToro indicated that volatilization might be a process of some importance to long term fate.

Thomann and Kontaxis (1981) developed a model of Waukegan Harbor (the study area) which was documented in a U.S. EPA Project Report, but not published in the scientific literature. This model had more detailed physical definition, but similar solids and PCB kinetics as the models previously discussed. This model of PCBs in Waukegan Harbor was formulated to estimate the export of PCBs under present conditions. The model also evaluated response to various incremental remedial actions. These evaluations defined the magnitude of the expected response in harbor PCB levels to remedial action goals. Additionally, the model demonstrated that concentrations of PCBs in the nearshore area were only slightly affected and in-lake concentrations beyond 750 meters from the harbor mouth were not impacted appreciably by the remedial alternatives.

Since the risk assessment conducted in this study requires confirmation of past evaluations as well as additional assessments, a mathematical model of PCB fate in the vicinity of Waukegan Harbor has been developed, calibrated and applied herein. The specific model framework described in Section 5.2. However, the model kinetics are very similar to the efforts discussed above. The model is used to examine the response in PCB levels in water and fish for two remedial action scenarios. PCB transport from water to the atmosphere via volatilization is also examined as a consequence of these actions. These results define the potential exposure to PCBs which are used to estimate the potential impact of the alternative remedial actions on human health. Model results also yield insight into the physical nature of the harbor and help identify the prominent processes which influence the fate (movement and longevity) of PCBs in the harbor and nearshore waters.

5.2. Model Framework

5.2.1. Kinetics

The fate of PCBs in aquatic environments is closely tied to the dynamics of resident solids because of the hydrophobic (lipophilic) and hence adsorptive nature of PCBs. The reactivity of PCBs, both chemically and biologically, also influences the fate and longevity of PCBs in the environment. Since the principal exposure of PCBs to humans is through the food chain, the bioconcentration of PCBs in fish is of interest in an assessment of risk. For these reasons the model framework discussed below is presented in three parts. These include: 1) Solids Dynamics; 2) PCB Kinetics; and 3) Fish Bioconcentration.

General characteristics of the PCB model include:

- Time-variable and steady-state simulation
- Hourly calculation
- Two-dimensional segmentation
- Total, particulate, and dissolved PCBs simulations
- Water and fish PCB levels modeling
- State-of-the-art PCB kinetics
- Atmospheric load calculations

The specific aspects of the model framework and the segmentation of the study area are presented in the remainder of this section.

Solids Dynamics: The dynamics of solids in aquatic environments substantially influence the fate of hydrophobic hydrocarbons, such as PCBs. PCBs adsorb to solids and then become subject to the fate of the resident solids. Therefore, the ultimate fate of many partitioning, persistent organics is in the sediment layer underlying water bodies. The PCB model simulates the dynamics of solid concentration in a water column ([Solids]) as a function of time as indicated in the mass balance equation:

$$\text{Change in [Solids]} = \text{External loading} + \text{Sediment loading (Resuspension)} - \text{Advective outflow} - \text{Settling} \pm \text{Dispersive exchange}$$

The solids transport simulated by this mass balance affects the fate of particulate PCBs.

The Waukegan Harbor site is principally an in-place pollutant situation. Active external sources to the harbor have essentially ceased. Therefore, the only remaining source of PCBs to the water column is from sediment loading due to resuspension of contaminated sediment. A competing process is the settling of solids. Settling of solids from the water column is an important process in Waukegan Harbor since the harbor is a known depositional zone. Approximately 475,000 kg of solids are estimated to be deposited within the harbor each year (Thomann and Kontaxis, 1981).

The magnitude of these two solid transport processes are determined by calibration to field data. However, the calibrated coefficients must remain within the range of values characteristically evaluated for settling and resuspension. These considerations and others are discussed in the Model Calibration section.

PCB Kinetics: The kinetic structure applied in the study is similar to previous studies of PCB fate in Lake Michigan and elsewhere (Rodgers, 1982; Thomann and Kontaxis, 1981; Thomann and Ditoro, 1983). A schematic diagram of the PCB kinetics and transport mechanisms is presented in Figure 5-1. The mass balance for PCBs in the water column over time is simulated as:

Change in [PCBs] = External loading + Sediment loading (Resuspension)
$\pm$ Dispersive exchange - Advective outflow - Volatilization
- Settling

This mass balance for PCBs is similar to that presented for solids, except for the inclusion of volatilization. An important feature of this mass balance equation is that some processes, like settling, impact only the particulate fraction of PCBs, while volatilization operates only on the soluble fraction. Therefore, the model must differentiate between particulate and soluble fractions of PCBs. Calculation of these two fractions is dependent on the assumption of equilibrium kinetics when describing adsorption and desorption phenomena. Based on an equilibrium assumption, a partitioning coefficient (pi) emerges which describes the ratio between PCBs adsorbed on the solids versus that portion in the water at equilibrium. This assumption is a part of contemporary models of PCBs and is valid for typical site and management evaluation.

Using equilibrium kinetics of PCB adsorption the dissolved (d) and particulate (p) fractions of total PCBs can be described, respectively, as:

$$[PCB]_d = [PCB]_{total} \left(\frac{1}{1 + pi\ [Solids]} \right);$$

and

$$[PCB]_p = 1 - [PCB]_d = \frac{pi\ [Solids]}{1 + pi\ [Solids]} [PCB]_{total} \cdot$$

The selection of the value for pi and other model coefficients is described in Model Calibration.

Volatilization is the process of a contaminant (e.g. PCBs) moving from one physical phase (*e.g.* aqueous) to another phase (*e.g.* gas) due to a concentration gradient overcoming an interface resistance. The transfer process from water to atmosphere is dependent on the chemical and physical properties of the chemical, the physical properties of the water body and atmosphere, and the influence of other pollutants. The properties of the chemical that control volatilization rates are its solubility, molecular weight and vapor pressure. Modeling of the process frequently utilizes a two-layer film resistance formulation (Liss and Slater, 1974). The model simulates volatilization as a diffusion process where the mass transfer coefficient (K_L) is the sum of the resistance of the liquid phase and the gas phase. A review of literature values and theoretical derivation of volatilization rates are presented in the Model Calibration section.

Fish Bioconcentration: PCBs are known to be distributed among all environmental compartments. Therefore, many potential human exposure routes exist. Yet, the principal exposure route has been shown to be typically via the consumption of contaminated fish (USEPA, 1980). This is so because fish are known to bioconcentrate lipophilic hydrocarbons such as PCBs. As a result, the ratio of the mass of PCBs per mass of fish will exceed many fold the mass of PCBs per mass of ambient water. There is a substantial data base identifying levels of PCBs in Lake Michigan fish. A bioconcentration factor (BCF) for these fish may theoretically be calculated as:

$$BCF = P_F/P_W$$

where

P_F = PCB level in fish (mg/kg)

P_W = PCB level in water (mg/ℓ).

The EPA (USEPA, 1980) assessed the value of a bioconcentration factor (BCF) as being 31,200 (mg/kg - wet fish weight per mg/ℓ PCB in the water) through laboratory evaluations. This BCF figure is an average for a "variety of saltwater and freshwater organisms." Derivation from field data is difficult because "the exposures of the organism cannot be adequately documented and integrated..." (USEPA, 1980-p. C-13). However, Rodgers and Swain (1983) reviewed available fish levels of PCBs in the upper Great Lakes and estimated a range of concurrent water levels. The calculated BCFs ranged from fifty thousand to several million. The large range in estimated values was principally due to the uncertainty of PCB levels in the ambient water.

Estimation of future PCB levels in fish can be calculated through multiplication of a representative BCF with projected water levels. Special consideration should be given to the application of the BCF to specific areas where the fish population is transient due to migration. For the OMC study area, the seasonal distribution of fish becomes important in the assessment of risk because only a small percentage of fish will reside in the areas significantly impacted by the site, and then only for a portion of the year. Direct application of the BCF to the levels of water column PCBs projected for the study area would probably result in overestimates of the fish PCB levels and, ultimately, unreasonable estimates of associated risk.

Extensive site specific data would be required to establish a BCF that would account for the transient nature of fish in the study area.

Because site specific fish and concurrent water data are virtually nonexistent, the BCF determined for Lake Michigan must be relied upon. However, the BCF equation can be modified to account for the fraction of time that fish will be exposed to the levels attributable to the OMC site.

If it is assumed that the fish will reside in two areas with different ambient water PCB levels, the BCF can be modified through the incorporation of residence weighting factors that represent the fraction of time that a percentage of fish will reside in the respective areas. The final calculation of the PCB level in fish (P_F) is represented as:

$$P_F = (t_1 * P_{W1} + t_2 * P_{W2}) * BCF$$

where

t_1 = the residence weighting factor representing the fraction of time that fish reside in area 1

t_2 = the residence weighting factor representing the fraction of time that fish reside in area 2

P_{W1} = the average ambient water PCB level for area 1

P_{W2} = the average ambient water PCB level for area 2

The values for the equation parameters are derived in model application and therefore are discussed elsewhere.

5.2.2. Model Segmentation

A mathematical model framework is composed both of kinetic and physical components. The kinetic components were discussed previously. The physical representation that is used in a model is guided by several site and problem specific characteristics, including:

1. physical dimensions;
2. topography;
3. variability of the contaminant distribution;
4. spatial resolution of management inquiries;
5. computational considerations.

Incorporation of these characteristics into a proper segmentation scheme for the study site is dependent on the expertise of the model developer. However, the performance of the model to simulate available field data and to answer intended management questions provides an objective assessment of the appropriateness of the segmentation.

The model segmentation selected in this study for Waukegan Harbor and the lake in the vicinity of the harbor is presented in Figure 5-2. The study site is about 2.2 kilometers (1.4 miles) east to west by 2.6 kilometers (1.6 miles) north to south. The site is divided into 37 segments. The harbor channel is composed of the initial 12 segments, while the remainder of the study site is defined by 25 segments. All segments are considered completely mixed. The underlying sediment layer was considered to interact with the overlying waters with no horizontal movement of the sediment bed. Transport between segments includes both advective and dispersive processes. The definition of this transport is related in the model calibration section. Both the physical segmentation and transport scheme of the model are very similar to those applied in EPA's evaluation by Thomann and Kontaxis (1981).

5.3. Model Calibration

In order for the model to be useful and reliable as a predictive tool, it must be able to accurately simulate the site-specific fate and transport processes of the system. Determination of the transport and kinetic parameters as well as a demonstration of the model validity can be achieved through model calibration. This section presents a discussion of the methods and results of the independent calibrations of hydrodynamic transport parameters, solids transport parameters, and PCB fate parameters.

The data used for the calibration were collected prior to 1981. Lack of a complete set of recent data precluded calibration to present conditions. However, water data for two locations in the harbor have been collected monthly over the past nine years. An analysis of this data indicates that the average PCB levels in the harbor have decreased approximately 50% since 1980. A discussion of this analysis is provided at the end of this section.

5.3.1. Hydrodynamic Transport

The fate and estimated export of PCBs from the harbor is dependent on the horizontal transport of the water throughout the study area. In particular, transport across the interface of each model segment must be specified. Definition of the transport phenomenon was calibrated by examining the dye survey conducted by Argonne National Laboratories on

June 4-11, 1979. A known mass of dye (238 grams) was released in the inner harbor (Segment 2). The horizontal transport coefficients of the model were adjusted until the model output for the conservative dye best fit the field data measured during the survey week. The model fit is evident in Figure 5-3 where model output (solid line) is plotted with the field data. Of particular note is that during the first day of simulation when the dye exhibits the greatest gradient, the model simulates the harbor gradient quite well. In addition, the horizontal transport calibrated in this study is quite similar to that reported by Hydroqual (Thomann and Kontaxis, 1981) as is evident in Figure 5-4. The horizontal transport is considered by both studies to be sufficient to describe the long-term hydrodynamic transport of PCBs in the study area.

5.3.2. Solids Transport

Since the fate of PCBs is closely associated with the transport of solids, determination of the solids dynamics is an important component of the model calibration. Witnin the water column there are two competing processes affecting the vertical fate of suspended solids. These are settling of solids from the water column and resuspension of solids from the sediments to the overlying water. The settling rate has been calibrated in many models for a number of different sites. The settling rate is dependent on the physical characteristics of the solid particles, including size, shape, and density. Settling of particles is therefore not as site specific as it is particle specific. Settling rates are most commonly between 0.5 and 2.5 meters per day. After testing settling rates within this range for the entire study area, a settling rate of 1.0 meter/day proved to be representative of the observed solids. This rate has some degree of uncertainty within the stated range, however Thomann and Kontaxis (1981) also identified this settling rate.

The resuspension rate is more a function of the site than the particle characteristics, although both play a role. The scouring action which resuspends the sediment is dependent on the energy forces at the sediment/water interface. This force is related to wind conditions, water velocity, and depth of the water column. The net result of these forces on resuspension is made evident by the level of suspended solids and PCBs in the water column. The magnitude of external loadings of solids due to direct drainage is relatively small, therefore observed suspended solids reflect net settling and resuspension of solids between the water column and the sediments. The horizontal transport of solids also plays a role, but has been defined by the hydrodynamic calibration to the dye survey. Therefore, the resuspension of solids in each segment is calibrated so as to best fit observed field data. Since the resuspension of solids with the inner harbor also accounts for the sources of PCBs to the water column from the in-place pollutants the resuspension must also fit available PCB data as will be seen in the following section.

Figure 5-5 presents the model output of suspended solids as compared with field data collected during May of 1979. The model fit simulates both the magnitude and trend of the available data. Thomann and Kontaxis (1981) noted that Waukegan Harbor is a net depositional zone for several hundred thousand kilograms of solids each year. This study confirms the observation and notes that a relatively small proportion of solids resuspended in the inner harbor is transported to the nearshore zone of Lake Michigan. Instead, these solids predominantly resettle within the harbor, while solids originating from the lake are also deposited within the harbor.

5.3.3. PCBs

Two major processes, hydrodynamic and solids transport, which affect the fate of PCBs have been calibrated so as to simulate dye and solids data. Based on the model framework discussed previously and the physico-chemical nature of PCBs only two processes remain which significantly impact the levels of PCBs in Waukegan Harbor and the transport of PCBs out of the harbor. These processes are the equilibrium partitioning of PCBs between solids and water and the volatilization of soluble PCBs from water to the atmosphere.

The partitioning of PCBs between solids and water in natural systems has long been recognized as being an important process in determining the fate of PCBs. In fact, partitioning of PCBs onto solids and the subsequent burial of these solids in the sediment layer is a major loss process of PCBs from the aquatic and biotic environments. Partitioning is modeled as an equilibrium phenomenon. As discussed in the Model Framework section, partitioning is therefore described by a singular coefficient (pi). A value for pi of 100,000 ℓ/kg was used in the water column and 10,000 ℓ/kg in the sediment layer. These values reflect values used in other modeling efforts discussed previously and the model results are not sensitive to a reasonable range of uncertainty in the value.

The remaining process of interest, volatilization, represents the movement of PCBs across the water/air interface and was discussed in the Model Framework section. The rate of volatilization in natural systems is a subject of ongoing scientific investigation. The theory is well established, but the capability of actually measuring the flux of PCBs at the water/air interface is nonexistent. The volatilization rate in this study was derived from theoretical considerations and affects only the soluble fraction of PCBs in the water column. When the water levels of PCBs are relatively high the typical levels observed in the atmosphere do not significantly impede the transport across the interface. A review of estimates for K_L, the mass transfer coefficient, revealed a range of 0.00875 to 0.099 m/hr. In this study the selected "best estimate" theoretical rate 0.057 meters per hour was chosen because it approximates the median value and reflects the findings of Mackay and Leinonen (1975). However, when water levels are below 100 ng/ℓ the atmospheric levels of PCBs theoretically begin to exert significant resistance to diffusion. This resistance was estimated to reduce volatilization by approximately one-half. Therefore, outer harbor and lake segments have an estimated volatilization rate of 0.0285 m/hr. The impact of these rates and others are discussed in the Model Projections section. It is important to note that although volatilization is a loss mechanism to the water, it conversely is a source mechanism to the atmosphere. Both impacts are discussed later.

Comparison of Model Results to 1980 Data: The model framework and the calibration of model coefficients have been discussed. Figure 5-6 presents the model output along with the field data for 1980 and demonstrates a very good model fit. Both the magnitude and spatial trend of the PCB data are well simulated. The model projects the range in the soluble fraction of PCBs to be approximately 65-80% within the harbor, which approximates values reported from the survey of 45-90%. The isopleth diagram (Figure 5-7) depicts the results of the model calibration for PCBs in the water column of the harbor and nearshore area of Lake Michigan. The paucity of data precluded comprehensive model validation for the nearshore and offshore zones of Lake Michigan. However, the model parameters and results are reasonable and compare well with previous modelling efforts and values reported in the literature (Thomann and Kontaxis, 1981). As can be seen by the results, the impacts of the harbor and North Ditch are confined to a relatively small area of the nearshore lake. For this modelling analysis, the North Ditch was modelled as a constant load to the nearshore zone. An average flow of 1.8 cubic feet per second (cfs) and a PCB concentration of 7 ppb were used to calculate the North Ditch load. These values were reported by Noehre and Graf in a 1980 EPA administrative report and are considered very conservative (high). For instance, an alternative flow of 0.4 cfs was reported by Thomann and Kontaxis (1981).

The export rate calculated from the calibration results indicates that 7.7 kg/yr of PCBs were transported from the harbor under average steady-state conditions. This result compares well with previous estimates of between 4 and 10 kg/yr from the harbor (Thomann and Kontaxis, 1981). The total load from the harbor and North Ditch during calibration conditions (1980) represents less than 0.6 percent of the total load from all sources to Lake Michigan as estimated by Rodgers (1983).

Evaluation of Recent Data: The model includes known loss processes such as settling, sediment burial, volatilization and washout. These process terms would logically reflect a time dependent reduction of PCBs in the surficial sediments and water. Therefore available water column data for the period after the calibration (1980-1986) were examined for evidence of this time dependent response. While the analysis of these water data indicate that reduction in system PCB levels has been observed over the last nine years, temporal surficial sediment data do not exist to confirm this trend. Therefore, the natural recovery trend was not considered in the model applications and the 1980 calibration conditions form the basis for the model analyses. However, since the available data indicate a declining trend, it is of interest to quantify this trend in order to determine the potential time-variable behavior of the system. Therefore, a regression model is applied in this analysis. A regression model was applied to temporal water data for two locations in Waukegan Harbor. The data were collected and analyzed as part of the requirements of OMC's NPDES permit. The water samples were collected monthly from two cooling water intake pipes; one located in Slip #3; the other in the upper harbor across from Slip #1. The natural logarithms of data are displayed in Figures 5-8 and 5-9.

A linear regression analysis using the least-squares method was performed on the natural logs of the data versus time. The "best-fit" lines are shown in the figures. The linear regression was performed on the logs of the data because sediment model theory and observed trends indicate first-order loss kinetics. Since the sources of PCBs to the sediments have been substantially curtailed, the mass balance equation for PCBs in the sediments can be simplified to a first-order loss equation. This first order loss kinetics is supported by similar declining trends of PCBs observed in the sediments of Lake Michigan (Rodgers, 1982), and the Saginaw River (Limno-Tech, Inc., 1983). Additionally, Thomann and DiTorro (1983) observed that plutonium in Lake Michigan sediments, which behaves similar to PCBs, exhibited similar trends following a sharp decrease in loads.

The results of the regression analyses are summarized below and indicated declining trends in both sets of data. Statistical T-tests were also performed on the data that confirm, with greater than 99% probability, that there are declining trends in both data sets.

Data Set	Slope of Best Fit Line	Correlation Coefficient (r^2)	Results of T-Test Probability That Declining Trend Exists
Slip #3 Intake	-0.191	0.144	>99%
Upper Harbor Intake	-0.0896	0.05	>99%

The correlation coefficients calculated for the best fit lines demonstrate the wide variability of the data. This data scatter probably results from variability in the resuspension forces that control the water column PCB levels. Wide variability in the resuspension rates for any given year, is expected due to the dynamic and complex hydraulics of the system.

Factors that contribute to this complexity include the transient impacts of the storms, variable lake levels that result in seiches, boat traffic, and temperature driven currents. However, the data indicate that the average as well as maximum PCB levels have decreased significantly since 1980, and the most probable rate of decline is described by the best fit line. The regression line indicates that the levels of PCBs have decreased 50% since 1980.

The declining trend is presumably attributable to the elimination of sources and natural recovery processes occurring in the surficial sediments. The principal natural recovery process is solids deposition resulting in sediment burial. Under the assumptions that the trend will continue and the levels of PCBs in Waukegan Harbor are declining according to first-order kinetics, a "half-life" can be calculated from the slopes obtained through the regression analyses presented above. The "half-life" is the time required for the levels of PCBs to decrease 50% from an initial condition. The calculated half-lives for the two locations in Waukegan Harbor are 3.6 years at Slip #3 and 7.8 years in the upper harbor. Extrapolation of these calculations indicate that the system PCB levels will be reduced by 50% every 4-8 years.

5.3.4. Fish Burden

The level of PCBs in fish are related to the level of PCBs in ambient water by a bioconcentration factor (BCF) as discussed in the Model Framework section. Estimated BCFs are known to vary for a variety of reasons including:

- Fish species
- Fish age (size)
- Percent lipid content
- Percent soluble PCBs in ambient water

Thomann and Kontaxis (1981) estimated a BCF of 6.3×10^5 ℓ/kg for their Waukegan Harbor study and demonstrated that this value simulated the observations observed in fish in 1978, but tended to overpredict levels observed in July 1979. Rodgers and Swain (1983) estimated BCFs for fish in the upper Great Lakes and found the values to be a function of fish species. These BCFs ranged from approximately 1×10^6 ℓ/kg for bloater chubs to 4×10^6 for lake trout. The present study examined fish data reported for four species of fish collected between 1979 to 1982 by several investigators and for two groups of fish collected in 1984 by the states which border Lake Michigan (see Chapter 3).

Estimation of the BCF requires knowledge of ambient water concentrations which influenced the fish levels. These water levels can only be estimated by ranges observed in Lake Michigan. Armstrong (1986) measured PCBs throughout Lake Michigan and observed an average concentration in the water column of 1.83 ng/ℓ from samples collected in 1981. Based on trends observed in Lake Michigan (Rodgers and Swain, 1983) these levels would have been higher prior to 1981 and lower in 1984. Taking all factors into consideration this study estimated that a BCF of 1×10^6 ℓ/kg was the most representative value for Lake Michigan simulation. This value would yield higher values for fish contamination than Thomann and Kontaxis (1981) estimated using a BCF of 630,000 ℓ/kg, but it is a reasonable representation of likely bioconcentration for a range of indigenous fish. It should be noted that this study's BCF value is more conservative (higher) than that used by EPA (USEPA, 1980) and Thomann and Kontaxis (1981). Using this study's BCF and the water concentration observed by Armstrong of 1.83 ng/ℓ, fish in Lake Michigan are projected to have a PCB body burden of 1.83 ppm, which compares very well with the 1984 fish data of 1.14 ppm for salmon and 2.60 ppm for trout.

5.4. Model Application

Projection of the distribution of PCBs in the study area during and after the implementation of proposed remedial actions is an integral component of estimations of risk associated with each action. The PCB model serves as a powerful predictive tool for the simulation of potential system impacts and responses to remedial action. Previous modeling investigations have demonstrated the expected system responses to various incremental levels of remedial effort (Thomann and Kontaxis, 1981). However, the model was not applied to estimate system responses to specific remedial actions. It is the purpose of the study presented herein to expand the model applications to examine the potential ramifications of two specific methods for the clean up of the OMC site. The modeling investigations include projections of PCB distribution during and after the implementation of these actions. From these projections, the magnitude of various human exposure routes can be estimated. Ultimately this will provide necessary information to estimate the risks associated with each action.

The remedial methods that were examined included: 1) The plan of action outlined in the Record of Decision (ROD), and; 2) The plan of action described herein as the in-place containment alternative (IPC). Descriptions of these plans of remediation are presented in Chapter 4. For both of these alternatives (IPC and ROD), simulations were conducted to estimate the system responses both during implementation and after the completion of the alternative.

The results of these investigations are reported below and the presentation is divided into two categories. The categories include:

1. Modeling projections for estimation of the system responses upon completion of the remedial actions (steady-state, "long term" responses).
2. Model investigation results for the estimation of impacts to the system during the implementation of the remedial action ("short-term" impacts).

Within each of these subsections, the model representations of the two remedial alternatives (ROD and IPC) and the assumptions that were made to simulate these alternatives are summarized. The modeling results for the two alternatives first examines PCB distribution in the water column. From these distribution results, and based on bioconcentration and residence weighting factors, the expected response levels of PCBs in fish will be calculated for the long-term impacts. Estimations of the export of PCBs from the harbor and North Ditch Area to Lake Michigan are then presented for each alternative during and after implementation. Estimations of the impact of the OMC site on the average concentration of PCBs in Lake Michigan are also presented. The final topic that will be discussed is the estimation of volatilization of PCBs from the areas of concern within the study site during and after implementation of the remedial alternatives.

5.4.1. Long-Term Projections

The modeling investigations that are reported in this sub-section represent estimations of the system response after the remedial alternatives have been implemented. The results reflect the expected PCB distributions in the water column in the time span following completion of the alternatives and after the PCBs in the water column have responded to the remedial action. Projections of total PCB concentrations were based on the model parameters established in the calibration of the model. It is assumed that the calibration conditions are representative of average conditions of the system. Efforts were made to apply the model in a consistent manner for the examination of each alternative. Any uncertainties in the model parameters and framework should apply to all projections with approximately equal magnitude. Therefore, it is believed that the model projections provide a strong base for comparative analysis of the responses to each action.

5.4.1.1. Model Representation

Projection of system response to specific remedial alternatives requires evaluation of the influence that a particular alternative will have toward reducing the loads to the system. The modeling investigations presented in this section were designed to estimate the response of the system to expected efficiencies of each alternative in isolating the PCB laden sediment from further interaction with the system. Model inputs utilizing the most reasonable set of assumptions to reflect remedial efficiency were developed for each remedial action. The assumptions and model inputs incorporate an integration of many factors that are variable and uncertain. Best professional judgement was utilized to integrate these factors to establish scenarios that are considered reasonable. These results are presented as the "best estimate" results and were calculated using the calibrated model coefficients discussed previously. Due to the uncertainty associated with alternative remedial assumptions, conservative approaches were often necessary. Additionally, model investigations were conducted for each action using a range of alternative assumptions regarding the details or effect of implementation of the action. These ranges do not span the entire imaginable range of uncertainty associated with the model projections, however, they reflect best professional judgement and represent a reasonable range of expected results.

The assumptions that were made in the development of the "best estimate" projections and projected ranges are summarized below for both the ROD and IPC alternatives.

ROD Alternative Representation

Under the ROD alternative, Slip #3 and the upper harbor as depicted in Figure 5-10 would be dredged for the removal of PCB contaminated sediments. A cofferdam will be utilized for the excavation of the deep contaminated sediments in the area denoted as "A" on Figure 5-10. Water that flows through the North Ditch would be rerouted through a drainage pipe and the contaminated sediments in the North Ditch area would be contained. Further details of the ROD alternatives are provided in Chapter 4.

Three cases were modeled for the ROD alternative that represent a range and best set of assumptions with respect to the expected methods and efficiency of the alternative in removing intended contaminated sediments. The assumptions for each case are summarized in Table 5-1.

The effectiveness of the ROD alternative in preventing the remaining PCBs from continued exposure to the environment is strongly dependent on the methods employed and the subsequent efficiency of removal. The efficiency of removal could vary appreciably due to the uncertainty associated with the execution of the dredging operations. These uncertainties arise because of the difficulties in achieving 100% removal of sediments through dredging. Factors such as resuspension of sediments during dredging operations and the sediments that are "missed" by the dredge preclude the removal of 100% of the sediments. Furthermore, the cost of dredging increases as the designed level of efficiency is increased. This increase in cost is due to the extra operational care and number of passes required. Indications are that most dredging operations achieve much less then 90% removal of sediments and that 90% removal is a level considered to be at the upper boundary of achievable removable efficiency. Due to the high levels of contamination, it is reasonable to assume that extreme care will be exercised during dredging operations. Ninety percent removal efficiency was considered a reasonable estimate that accounts for the care that will be exercised but also reflects the limits of efficiency levels that are practically achievable. The three cases that were modeled represent sets of assumptions with respect to the methods employed and degree of care during removal operations.

The "best set" of assumptions reflect the case where a cofferdam would be built to encompass all of area "A" depicted in Figure 5-10 and that fill material would subsequently cover the area, thereby effectively isolating 100% of the remaining contaminated surficial sediments in area "A". Ninety percent removal efficiency through dredging of the remainder of slip #3 and the upper harbor was considered a reasonable assumption and reflective of a high level of operational efficiency. The "high estimate" case assumed that 10% of the contaminated sediments in Area "A" would remain exposed to the overlying water column after the dredging was completed. Under this scenario it was also assumed that 90% removal of the sediments in Slip #3 and the upper harbor would be achieved. This "high estimate" case does not address worst case expectations but rather reflects a reasonable upper bound for extremely careful implementation. If extreme care is not exercised, the resulting exposure levels could be significantly higher. The "low estimate" case assumes the difficult and unprecedented engineering result that the dredging operation will be nearly 100% efficient and will achieve removal to 50 ppm throughout the area to be dredged.

In the North Ditch Area it was assumed that the ROD alternative would effectively isolate the contaminated sediment from interaction with the environment. For both the "best set" of assumptions and the low estimate cases, the loads to the water column in this area were considered to be negligible. The "high" estimate case assumed that minor leaching through the slurry walls would occur and 0.6 lbs/year PCBs would be transported to Lake Michigan via groundwater flow. This loading rate was considered a reasonable and conservative estimate based on calculations reported by Westin Consultants - Designers (1982) and Mason and Hanger-Silas Mason Company (1981). All other model parameters were assumed to be the same as in the calibration.

IPC Alternative Representation

The IPC alternative entails the construction of a retaining wall at the mouth of Slip #3 and using this area as a containment cell for sediments dredged from the upper harbor. The wall will be constructed down to glacial till and should serve as an effective barrier isolating the PCB laden sediments in Slip #3 from interaction with the harbor. In the North Ditch area, the water flowing through the North Ditch will be rerouted through a storm pipe and the North Ditch will be back filled. The area will be graded for drainage to this pipe. Additionally, the groundwater in the vicinity will be monitored for PCB migration, and an assessment will be made of the need for further action to minimize migration.

Two scenarios of assumptions for the IPC alternative were examined. Assumptions for these cases are listed in Table 5-2. The "best estimate" case reflects the assumption that the wall at Slip #3 will prevent the load of any PCBs originating from the slip from entering the harbor. Ninety percent removal efficiency of the sediments in the upper harbor was considered reasonable. The action proposed for the North Ditch area was considered to be effective in reducing the loads from this area to negligible levels. Groundwater monitoring should allow for the assessment of need for further remedial action in this area and it was assumed that further action would be implemented if necessary.

The high estimate case considers the assumption that migration through the ground water will occur in both the harbor and North Ditch areas. For Slip #3, a loading rate of 0.6 lbs/yr was assumed based on estimations by Weston Consultant-Designers (1982). For the North Ditch Area, it was assumed that actions implemented in this area would reduce loads similar to the ROD actions. Therefore, the ROD "high estimate" loading rate of 0.6 lbs/yr was used.

5.4.1.2. Model Results

Under the assumptions presented above, the model was applied to estimate PCB distributions upon completion of the remedial alternatives. For each alternative, projections were made that represent a range of variability associated with the estimated effectiveness of the alternatives. Model results that reflect the set of assumptions considered through best professional judgement to be most likely or reasonable are presented as "best estimates." The results of the modeling investigations are presented below in three parts. The first part presents expected PCB distributions in the water column for each alternative. The second and third parts present calculated PCB levels in fish and estimations of export rates, respectively. These were derived from the projected water column distributions.

Water Results

Model runs were conducted to independently define the impacts of Waukegan Harbor on the PCB distribution in the water column for the entire study area. It was of interest to discern the contribution of PCBs solely attributable to Waukegan Harbor and North Ditch sites following remedial action. In order to define the impact from these sites a "base" case representing background conditions was first examined. The base case set the sediment concentrations in the harbor and North Ditch area equal to background levels for Lake Michigan. The results of this projection are presented in Table 5-3. This base case simulation can be utilized to assess the residual impacts attributable to the sites under various remedial action scenarios. The incremental impact remaining after implementation of remedial action is defined as the difference between the simulated concentration for the remedial action and the base case.

Examination of the results of this base case indicate that concentrations of the harbor are somewhat less than the nearshore and offshore zone of Lake Michigan. A similar trend was observed in the modeling analyses conducted by Thomann and Kontaxis (1981) for high levels of remedial action and indicates that under uncontaminated conditions, the harbor should act as a sink (depositional zone) for particulate PCBs transported from Lake Michigan.

The model projections of the average total PCB distribution for each of the alternatives are depicted in the isopleth diagrams (Figures 5-11 and 5-12). These results reflect the "best estimates" of the expected steady state concentrations upon completion of each alternative and were derived based on the "best" sets of assumptions. The results of the model simulations for the expected ranges of remedial action effectiveness are summarized in Table 5-4.

The results of the ROD alternative "best estimate" projections are presented in Figure 5-11. Table 5-4 summarizes the expected PCB concentrations for the various efficiency levels of removal that were considered. Recall that removal efficiency is a major factor in characterizing the three ROD sets of assumptions. As is evident from Table 5-4, the effectiveness of the ROD alternative is very sensitive to the efficiency of the dredging operation. As would be expected this sensitivity is especially apparent in the estimated removal efficiency of sediments in Slip #3. The results reflect the assumption that extreme care will be used during implementation and that at least 90% efficiency will be achieved. The predicted levels of PCBs could increase significantly if this level of efficiency is not achieved.

The results of the IPC alternative under the best set of assumptions is presented in the isopleth diagram of Figure 5-12. The results indicate that under the assumption that the wall will effectively isolate the contaminated sediments, the concentrations in the water column will approach "background levels" and the harbor will act as a sink for PCBs from Lake Michigan.

Fish

The projected response of PCBs in fish to the remedial actions is an important consideration with respect to future risks. The model projections for the distribution of PCBs in the water column are utilized to estimate expected PCB levels in resident fish. A discussion of the derivation of the bioconcentration factor utilized is presented in Section 5.2.

As discussed in Section 5.2, the seasonal distribution of fish should be considered in the calculations of expected PCB levels in fish caught for consumption near the study area. Modeling results indicate that the impacts attributable to the OMC site are confined to a relatively small area of Lake Michigan. Due to the migratory nature of Lake Michigan fish, the fish that are caught for consumption in the vicinity of the study area will probably be subject to elevated concentrations in their food supply and ambient water for only a fraction of their lives. A method of accounting for this transient exposure was presented in Section 5.2. The method employs resident weighting factors that influence the effective BCF. The resident weighting factors represent the fraction of time that fish will be subject to various area-specific levels of ambient PCB concentrations. The weighting factors were estimated based on interpretations of available fish distribution data that indicates that the fish caught in the vicinity of the OMC site will probably be exposed to the ambient conditions (both food supply and water) of the nearshore/offshore modeled areas for no more than 20 percent of their lives (10% nearshore and 10% offshore). These estimates are generalized but are considered conservative and reasonable given the paucity of data. A weighting factor of 0.1 for each lake area was therefore considered appropriate for application for the BCF equation. The assumptions and results of this distribution analysis are presented below.

The seasonal depth distribution of a variety of fish were estimated based on interpretations of data from Brandt (1978), Wells (1968) and Eck (1983). The data indicated that fish migrate seasonally and would be expected to reside in depths characteristic of the nearshore/offshore areas (0-10 m) for less than 20% of their lives (10% nearshore; 10% offshore). The data and review are presented in a study memorandum (Limno-Tech, 1986) and are summarized in Table 5-5.

The interpretation of this data included the following assumptions and observations.

1. The available fish distribution data is representative of conditions in the nearshore/offshore zone (0-10 m).

2. 90% of the PCBs in salmonids is attributable to food sources. Alewives sculpins and smelt are principal food sources to salmonids. Therefore, distribution of alewives, smelt, and sculpins should be a major factor in the exposure of salmonids to area specific PCBs.

3. The distribution of fish in the nearshore and offshore zones are equal.

4. The projections of water concentrations in the nearshore/offshore areas were derived by the PCB model.

The estimates of 20 percent exposure factor is considered very conservative due to the following observations:

1. Trout and salmon migrate along shore as well as offshore and, therefore, will be feeding on prey impacted by the site for considerably less than 20 percent of the year. Furthermore, the prey migrate along shore as well and probably are impacted by the OMC site less than 20 percent of their lives.

2. Waukegan Harbor is not conducive to spawning for trout and salmon since it has no tributary. Salmon and trout will preferentially migrate to other areas of the lake that are conducive to spawning.

3. The distribution of data for the fish probably yield over-estimates of the nearshore percentages since bottom trawls were used.

The estimates of the period that salmonids will be exposed to the ambient levels of the nearshore/offshore area can be refined only with extensive site specific data. The estimate of 20 percent is considered a rough but conservative approximation. The projected impacts of the OMC site on fish levels can be calculated for the nearshore and offshore zones (Figure 5-10) by applying a factor of 0.1 to the bioconcentration equations for each area. The remainder of PCB exposure will occur during the time that the fish reside in the main lake (80%).

Three factors derived above determine the projected concentrations in Lake Michigan fish associated with the remedial actions. These factors include: 1) the exposure levels; 2) the exposure time; and 3) the bioconcentration factor (BCF). The projected water concentrations reported in Table 5-3 and 5-4 yield the likely exposure levels. The exposure time is represented by the resident weighting factors derived above as 0.1 in the nearshore, 0.1 in the offshore, and 0.8 in the main body of Lake Michigan. Given this information, the third factor, the BCF, can be applied to all remedial scenarios to derive representative values for fish response to remedial alternatives (see section 5.2.1.).

Table 5-6 presents the model projections for PCB levels in resident fish in Lake Michigan for each scenario examined. These levels reflect fish exposure to the areas impacted by the OMC site and Lake Michigan. In order to isolate the influence of the OMC site on fish body burdens, the influence of Lake Michigan was set to zero. Table 5-7 presents the model projections of fish PCB levels attributable solely to their residing in areas impacted by the OMC site. As is evident from the results, all of the scenarios have little impact beyond the nearshore zone which is expected based on the water results and field observations.

5.4.2. Export Rates

The estimated net flux or export rates of PCBs from the harbor to the lake are presented for each alternative in Table 5-8. The export fluxes are based on the model projections discussed above and represent average steady state rates.

The calculated net flux rates indicate that the IPC alternative will be more effective than the ROD in reducing the transport of PCBs from the harbor. The export of PCBs out of the harbor under the IPC alternative will be negligible even if leaching occurs from the containment cell (high estimate). The amount of PCBs that are estimated to be transported under the ROD alternative are sensitive to the effectiveness of the dredging operations. If the dredging operation in Slip #3 is not 100% effective, then transport of PCBs from the harbor will continue at a significant rate (>0.4 kg/yr).

For the North Ditch area, the export rates after implementation of the remedial action are difficult to predict. Both remedial actions are projected to substantially alter the groundwater flow patterns and therefore reliable estimates of potential export rates cannot be determined without further study after the alternatives have been implemented. In the best set of assumptions for both alternatives, it was assumed that the actions would effectively reduce the export of PCBs from the North Ditch area to zero. The high estimate of export rates for the alternatives is 0.6 lbs/yr and was based on upper limit calculations of migration of PCBs through the slurry walls.

5.4.3. Projected Impacts During Implementation of Remedial Action

Projected long term responses of the study area to remedial action alternatives were discussed above. The implementation of these actions could have significant transient impacts that create short term increases in human exposures to PCBs. Included among the potential impacts are elevated levels of PCBs in the water column, increased transport of PCBs to Lake Michigan, and increased volatilization to the atmosphere. Because the impacts are short-term, the effects on fish body burdens, which are more impacted by lifetime exposures, were assumed to be negligible. It is the purpose of this section to present results of modeling investigations conducted to estimate the magnitude of the impacts on the water column of the study area. Expected volatilization rates during implementation are discussed in Section 5.5. area. Expected volatilization rates during implementation are discussed in Section 5.5.

The focus of the investigations presented herein is the impacts of the actions associated with dredging and excavation operations. It was assumed that impacts of other phases of implementation of the proposed remedial actions would be negligible. Dredging operations however can potentially cause significant disruption and resuspension of sediments. There is wide variability in the resuspension that may occur during dredging operations. Many factors contribute to this uncertainty including: type of dredge selected, operator care, methods of dredging, sediment characteristics, and system hydrodynamics. Additionally, uncertainties exist in the transient kinetics of contaminants associated with resuspended solids (e.g. desorption rates and volatilization rates).

Many assumptions were required in the calculations as a result of these uncertainties but the assumptions were carefully examined and the calculations provide valid estimations of the magnitude of impacts associated with the proposed dredging operations.

The calibrated PCB model described above was applied to calculate transient PCB distributions during dredging operations. Model representation and assumptions that form the basis of these calculations will be summarized below followed by a presentation of PCB distributions and estimated export rates.

5.4.3.1. Model Representation

Both the ROD alternative and the IPC alternative include plans for dredging of the harbor. However, the areas to be dredged are different. The ROD alternative calls for the dredging of Slip #3 and the upper harbor (depicted in Figure 5-10) whereas under the IPC alternative Slip #3 will be contained and only the upper harbor will be dredged. This difference is significant due to the extremely high levels of PCBs that are in the upper portion of Slip #3.

The modeling analysis was divided into two principal investigations: 1) expected impacts of dredging Slip #3; and 2) expected impacts of dredging the upper harbor. The combined results of these analyses represent estimations for the ROD alternative, and the results for the second investigation comprise the estimations of dredging impact for the IPC alternative. The construction of the containment wall under the IPC alternative was considered to have only minor effects on resuspension and therefore negligible impacts. This assumption was considered valid because of the methods to be employed, the short duration of installation, the relative small area of potential impact, and the lower level of contamination of the proposed containment wall site.

The amount of sediment that will be resuspended during dredging operations was considered the most critical factor in determining impacts to the system. Because of the uncertainties that exist with respect to this phenomenon, a range of estimates were developed. "Best estimates" that were judged to be the most likely were based on typical dredging operations and are considered representative of expected conditions.

The Army Corps of Engineers have compiled several studies that investigate the amount of resuspension that occurs during dredging operations (USACOE, 1984 and Wakeman *et al.*, 1975). These reports indicate that there is wide variability depending on, among other factors, dredge type used, dredge operator care, sediment characteristics, and system geometry and hydraulics. Increases in average suspended solids concentrations within several hundred meters of the dredge were reported to range from 10 - 1000 mg/ℓ. Additionally, there exists vertical and horizontal concentration gradients. Suspended solids concentrations decrease with horizontal and vertical distance from the dredge head.

Based on these studies and consideration of the specific characteristics of Waukegan Harbor, increases in suspended solids levels due to dredging were assumed. These assumed increases form the basis of this analysis. Average suspended solids levels in the vicinity of the dredge were assumed to increase to 10-80 mg/ℓ. A level of 40 mg/ℓ suspended solids was considered the best estimate and reflective of careful dredging operations. Model runs were conducted to determine the average resuspension rate and therefore the sediment loading rate necessary to create these suspended solids concentrations in the immediate area of the dredge. The calculated loading rates ranged from 1000 kg/d to 10,000 kg/d and represent approximately 0.1 to 3% of the sediment dredged.

Both alternatives call for a silt screen to be placed at the boundary between the upper and lower harbor to minimize export during dredging. In the model investigations it was assumed that the silt screen would be 90% effective in preventing transport of solids and PCBs. The effects of the screen was incorporated into the model framework through reducing the horizontal transport rate or dispersion coefficient at the boundary between cells 4 and 5. The dispersion coefficient was adjusted until approximately 90% reduction in solids transport was achieved. The estimated amount of solids transported through the silt screen represents approximately 4% of the original solids resuspended and therefore approximately 0.0041 to 0.1% of the dredged sediments.

both the steady-state and time variable version of the PCB model were utilized in the investigations. Comparisons of model results indicated that the system approached steady state very rapidly and therefore in order to simplify the calculations, the steady state model was predominantly used and considered an accurate approximation of impacts occurring on a daily time scale. The results of the two models differ slightly over the time frame considered (~15% over 6 days) but the difference is small in comparison to the uncertainties and well within the range of calculations.

5.4.3.2. Model Results

Incorporating the resuspension rates and dispersion coefficients derived above, expected PCB distributions during the dredging operations were calculated. The results are summarized in Table 5-9 for the ROD alternative and Table 5-10 for the IPC alternative. The estimations for the duration of dredging are based on estimates by Malcolm Pirnie, Associates (1982). The duration of dredging required for Slip #3 and the upper harbor is estimated to be 6-10 days and 40-50 days, respectively.

Slip #3: As is evidenced by the results, the dredging of Slip #3 could cause significant temporary increases in the water column PCBs throughout the study area. Because of the high suspended solids levels that are expected, most of these PCBs will be particulate and subject to settling. The projected levels of total PCBs range from 170 to 1800 $\mu g/\ell$ in the upper harbor and Slip #3. A substantial portion of these exposed PCBs are confined to this area due to the estimated effectiveness of the silt screens. However, levels of PCBs beyond the silt screen are predicted to be considerably elevated during the dredging of Slip #3, even under very optimistic conditions.

Export rates were calculated based on these model simulations and the results are presented in Table 5-11. The results indicate that under the model assumptions that approximately 1 - 12 kg of PCBs could be transported to Lake Michigan during dredging of Slip #3. This value is within the range calculated for transport for an entire year under present conditions.

The estimated impacts of dredging of the upper harbor are much less significant. This is primarily due to the much lower levels of PCBs associated with the sediments in this area. The projected water concentrations range from 2 - 17 $\mu g/\ell$ in the upper harbor and the decreases due to the effects of the silt screen result in relatively low levels evident in the outer harbor and lake. The calculations of export rates are presented in Table 5-11 and indicate relatively minor transport of PCBs during the dredging of the upper harbor, based on the estimated effectiveness of the silt screen and the isolation of Slip #3.

5.5. Volatilization

The PCB model was developed as a tool to enable scientifically valid forecasts of PCB fate in the study area. The model simulates both particulate and soluble PCBs in the water column. As discussed in Section 5.2, Model Framework, PCBs are not confined to the water column. These hydrocarbons may be transported with associated solids to the underlying sediment layer or may enter the atmosphere via volatilization. Volatilization is the process by which dissolved PCBs are transferred from the water phase to the air phase by molecular diffusion. The volatilization loads calculated here are the input loads to the air transport model examined in Chapter 6.

Once PCBs enter the atmosphere they are subject to atmospheric transfer away from the point of origin. The presence of PCBs in the atmosphere represents an additional exposure route to humans via inhalation. Normally, the risk associated with this exposure route is quite small, usually less than 1% of the likely exposure (USEPA, 1980). However, the remedial alternatives examined herein would create aqueous solutions having high levels of PCBs in an area with both public and occupational populations in nearby proximity. Therefore, the influence that volatilization has both on the loss of PCBs from the water and as a source of PCBs to the atmosphere was examined.

The general theory used in simulating volatilization was discussed previously and is examined by Liss and Slater (1974) and by Mackay and Leinonen (1975). Molecular diffusion theory conceptually perceives a process whereby molecules must overcome the resistance across two films -- the water and the air. Evidence of volatilization of PCBs has been observed in laboratory experiments as well as field observations (Thomann and DiToro, 1983).

The magnitude of volatilization is dependent upon the concentration gradient between the water and air compartments and the value of a mass transfer coefficient, K_L. The water concentration is calculated by the model for each of the remedial actions for all study locations. The best estimate of the mass transfer coefficient was identified as 0.057 m/hr as a value approximating the median of value calculated by theoretical derivations and as the value reported by Mackay and Leinonen (1975). However, because of the difficulty in measuring this value, a range of rates were examined. These rates were applied to two situations under examination in this study. First, Section 5.5.1 examines volatilization as an operative process during the long-term period following each of the remedial actions. Second, Section 5.5.2 evaluates the magnitude of this flux during the implementation of the remedial actions.

5.5.1. Long-Term Volatilization

This study examined the present conditions in the study area and two remedial actions (ROD and IPC). The model forecasted the concentrations of total, particulate, and soluble PCBs for each segment of the area during a long-term steady state period following each action. Using the model term for volatilization, a load of PCBs from the water to the air was calculated for each of the management scenarios. The best estimate simply utilized the best estimate for both the mass transfer coefficient (0.057 m/hr) and the predicted soluble concentration of PCBs. These loads are reported for each of the management scenarios for the areas of concern in and near the harbor in Table 5-12.

The long-term ROD remedial alternative volatilization load is calculated to be 5.38 lbs/yr and the IPC alternative results in a slightly lower load of 3.4 lbs/yr. The range of loads of PCBs to the atmosphere via volatilization is reflected in the minimum and maximum values reported in Table 5-12. This range reflects the sensitivity of the estimates due to possible variability in the volatilization estimates. Two factors considered in assessing this range were: 1) mass transfer coefficient (0.1-2.0 m/day); and 2) the expected alternative removal efficiencies as described in Section 5.4. The range of mass transfer coefficients was applied to each alternative under the "best estimate" for the removal efficiency. This required recalibration of the model to 1980 conditions in order to maintain a mass balance under altered loss rates. The "best estimate" (0.057 m/hr) of the mass transfer coefficient was then applied to the range of water concentrations derived from model projections of the various alternative removal efficiencies discussed above. The range presented in Table 5-12 reflects the combined sensitivity of the estimates due to both of these uncertainty factors.

5.5.2. Volatilization During Implementation

The loads of PCBs to the atmosphere during implementation of the remedial actions should be of special concern since dredging and dewatering activities would result in elevated levels of PCBs. Assessment of volatilization during remedial implementation must also consider the duration of different phases of each remedial alternative. Table 5-13 presents the expected atmospheric loadings of PCBs during implementation of the ROD action. The expected duration of the load is also indicated in Table 5-13. For instance, the 6-10 days indicated for certain areas of concern represents the estimated duration and exposure time for dredging the more highly contaminated areas, whereas 40-50 days represents the time for dredging the remaining areas. A similar table for the IPC alternative is presented in Table 5-14. There are fewer areas of concern associated with the implementation of the IPC alternative than for the ROD alternative because of differences in design. Since the IPC alternative by design disturbs less of the in-place contaminant sediments, there is less environmental exposure during implementation. This reduced environmental exposure during implementation is true for the ambient water quality as well as the resulting volatilization loads. The IPC alternative has not only lower total atmospheric loads but significantly smaller peak loads, which may be important when considering residential and local workforce exposure.

Table 5-1

Assumptions for the Steady State
Model Projections for the ROD Alternative

Best Estimate Case:

1. The cofferdam will be built encompassing the entire area A of Figure 5-1 and backfilling will allow the remaining sediments in this area to be 100% isolated.

2. 90% dredging efficiency for removal of sediments in the remainder of the area to be dredged.

3. Based on 1980 average sediment concentrations as reported in the Mason and Hanger Final Report.

4. The model parameters developed in the calibration are applicable and represent average expected conditions.

5. The load from the North Ditch Area will be negligible after completion.

Low Estimate Case

1. 100% removal of the sediments to 50 ppm in the entire area to be dredged will be achieved.

2. The load from the North Ditch area will be negligible after completion.

3. Assumptions 3 and 4 above apply.

High Estimate Case

1. 10% of the sediments will remain in Area A and will be exposed.

2. 90% dredging efficiency for removal of sediments in the remainder of the area to be dredged.

3. A small load due to migration through the slurry walls in the North Ditch area will flow to Lake Michigan via Groundwater (0.6 lbs/yr).

4. Assumptions 3 and 4 in the Best Estimate apply.

Table 5-2

Assumptions for the Steady State
Model Projections of the IPC Alternative

Best Estimate

1. The wall constructed at Slip #3 will effectively isolate the contaminated sediments from the harbor.

2. The dredging of the upper harbor will be 90% efficient in the removal of these sediments.

3. The actions proposed for the North Ditch area will reduce the loads to Lake Michigan to negligible levels.

4. The model parameters as developed in the calibration are applicable and represent average conditions.

High Estimate

1. Some migration of PCBs will occur from the containment cell in Slip #3.

2. The actions in the North Ditch Area will be as effective as the actions for the ROD in the prevention of PCB loads to Lake Michigan (0.6 lbs/yr).

3. Assumption 4 from above applies.

Table 5-3

Base Case Water Concentrations
without PCBs in Waukegan Harbor/North Ditch ($\mu g/\ell$)

Harbor	0.0007
Nearshore	0.0014
Offshore	0.0017

Table 5-4

Steady State Projections [PCB] in Water (ppb)

Ranges reflect estimated effectiveness of alternatives

Areas of Concern	Best Estimate	Minimum	Maximum
ROD Alternative			
Harbor	0.014	0.0019	0.027
Nearshore	0.002	0.0015	0.003
Offshore	0.00177	0.00177	0.0018
IPC Alternative			
Harbor	0.0009	0.0009	0.0043
Nearshore	0.0015	0.0015	0.0023
Offshore	0.0017	0.0017	0.0018

Table 5-5

Annual Average Percentage of Fish Caught by Trawl in 0-10 m Depth in Lake Michigan

Species	Annual Average Percentage of Fish Caught in 0-10 m Depth
Alewives	21.8
Smelt	15.5
Sculpines	0.5
Yellow Perch	28.0
Bloater Chubs	1.2
Lake Trout	< 5.0

Table 5-6

Steady-State Projections [PCB] in Fish (ppm)
Caught in the Vicinity of the OMC Site[a]

ROD Alternative

Best	Minimum	Maximum
2.0	1.9	2.1

IPC Alternative

Best	Minimum	Maximum
1.9	1.9	2.0

[a]Ranges reflect estimated effectiveness of alternatives assuming BCF = 1*E6((mg/g)/hg) and fish reside in the nearshore/offshore area for 20% of their lives.

Table 5-7

Concentration of PCBs in Fish Solely
Attributable to Areas Impacted by the OMC Site

ROD Alternative

		Best	Minimum	Maximum
Nearshore		0.06	0.01	0.16
Offshore		0.007	0.007	0.01
	Total	0.067	0.017	0.017

IPC Alternative

		Best	Minimum	Maximum
Nearshore		0.01	0.01	0.09
Offshore		0.0	0.0	0.01
	Total	0.01	0.01	0.10

Table 5-8

Calculated Export Rates for Transport of
PCBs from the Harbor for Alternative Scenarios

Alternative	Calculated Export Rates (kg/yr)
Record of Decision:	
Best Estimate	0.4
Low Estimate	0.008
High Estimate	0.8
In-Place Containment:	
Best Estimate	-0.02 kg/yr
Low Estimate	-0.02 kg/yr
High Estimate	0.08 kg/yr

Table 5-9

PCBs in Water During Implementation (ppb)

ROD Alternative

Areas of Concern	Best Estimate	Minimum	Maximum	Duration
Slip #3	913	186	1821	6-10 days
	1.15	0.24	2.4	40-50 days
Upper Harbor	836	170	1666	6-10 days
	8.5	1.74	16.9	40-50 days
Lower Harbor	6.6	1.3	13.3	6-10 days
	0.07	0.015	0.14	40-50 days
Outer Harbor	3.7	0.76	7.5	6-10 days
	0.04	0.01	0.08	40-50 days
Nearshore	0.20	0.075	0.40	6-10 days
	0.01	0.008	0.013	40-50 days
Offshore	0.023	0.008	0.036	6-10 days
	0.003	0.003	0.003	40-50 days

Table 5-10

PCBs in Water During Implementation (ppb)

IPC Alternative

Areas of Concern	Best Estimate	Minimum	Maximum	Duration
Slip #3	NA	NA	NA	40-50 days
Upper Harbor	8.5	1.74	16.9	40-50 days
Lower Harbor	0.07	0.015	0.14	40-50 days
Outer Harbor	0.04	0.01	0.08	40-50 days
Nearshore	0.01	0.008	0.013	40-50 days
Offshore	0.003	0.003	0.003	40-50 days

Table 5-11

Estimated Export of PCBs from
Waukegan Harbor During Dredging Operations

	PCB Export Rates	Duration	Total PCBs Transported
Dredging of Slip #3:			
Best Estimate	0.62 kg/d	6-10 days	3.7 - 6 kg
Low Estimate	0.12 kg/d	6-10 days	0.7 - 1.2 kg
High Estimate	1.26 kg/d	6-10 days	7.5 - 12 kg
Dredging of the Upper Harbor:			
Best Estimate	0.006 kg/d	40-50 days	0.2 - 0.3 kg
Low Estimate	0.001 kg/d	40-50 days	0.04 - 0.05 kg
High Estimate	0.013 kg/d	40-50 days	0.5 - 0.65 kg

Table 5-12

Steady State Volatilization Loads

Ranges Reflect Combined Sensitivities (lbs/d)

ROD Alternative	Best Estimate	Minimum	Maximum
Slip #3	0.00037	0.000018	0.005
Upper Harbor	0.0013	0.000073	0.0015
Lower Harbor	0.0034	0.0002	0.0035
Outer Harbor	0.00088	0.000075	0.0009
Nearshore	0.0048	0.0011	0.007
Offshore	0.004	0.00076	0.009
TOTAL	0.0148	0.00223	0.0269

IPC Alternative	Best Estimate	Minimum	Maximum
Slip #3	neg.	neg.	neg.
Upper Harbor	0.000056	0.0000086	0.0002
Lower Harbor	0.00021	0.000032	0.00055
Outer Harbor	0.000096	0.000013	0.00017
Nearshore	0.0051	0.00083	0.016
Offshore	0.0039	0.0007	0.005
TOTAL	0.00936	0.00158	0.0108

Table 5-13

Volatilization Loads During Implementation (lbs/day)

ROD Alternative

	Combined Ranges			
Areas of Concern	Best Estimate	Minimum	Maximum	Duration
Slip #3	1.38	0.1	2.07	6-10 days
	0.014	0.0011	0.02	40-50 days
Upper Harbor	6.44	0.5	9.64	6-10 days
	0.062	0.005	0.1	40-50 days
Lower Harbor	1.41	0.2	2.69	6-10 days
	0.0074	0.002	0.03	40-50 days
Outer Harbor	0.34	0.06	0.67	6-10 days
	0.0019	0.0005	0.004	40-50 days
Nearshore	0.83	0.2	1.5	6-10 days
	0.036	0.009	0.07	40-50 days
Offshore	0.052	0.017	0.08	6-10 days
	0.0066	0.002	0.011	40-50 days
Crescent Ditch	0.016	0.0014	0.028	< 1 year*
Oval Lagoon	0.008	0.0008	0.014	< 1 year*
E-W Channel	0.024	0.002	0.057	< 1 year*
Dewatering Lagoon-1	1.97	0.034	3.42	2 years**
Dewatering Lagoon-2	0.822	0.013	1.427	2 years**
Containment Cell-ND	2.77	2.22	3.32	< 1 year*
Containment Cell-PL	3.73	3.49	4.00	6-10 days*
Containment Cell-PL	0.280	0.280	0.344	40-50 days*

*Dewatering time and time before capping unknown, assumed to be less than 1 year.

**Sediments in Dewatering Lagoon-1 may be fixed to minimize volatilization. Actual volatilization rates may be lower due to attenuation through fixation and/or decreasing rates of exchange between sediment and water. Data were not available for quantification of this attenuation. Therefore, consideration of the range is recommended.

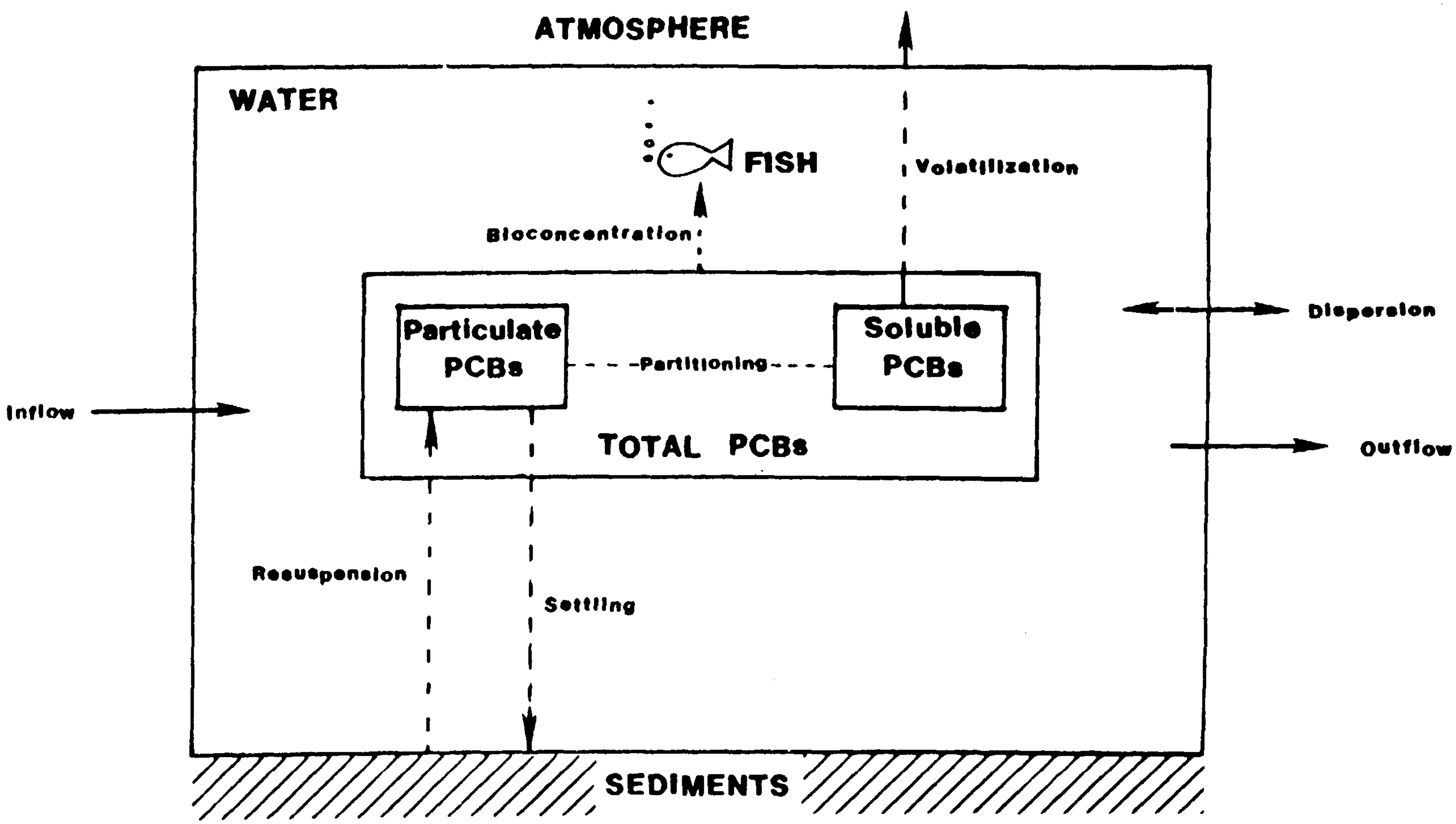
Table 5-14

Volatilization Loads During Implementation (lbs/day)

IPC Alternative

Combined Ranges

Areas of Concern	Best Estimate	Minimum	Maximum	Duration
Slip #3	0.281	0.0087	0.489	40-50 days
Upper Harbor	0.062	0.005	0.1	40-50 days
Lower Harbor	0.0074	0.002	0.03	40-50 days
Outer Harbor	0.0019	0.0005	0.004	40-50 days
Nearshore	0.036	0.009	0.07	40-50 days
Offshore	0.0066	0.002	0.011	40-50 days
Crescent Ditch	0.016	0.0014	0.028	150 days
Oval Lagoon	0.008	0.0008	0.014	150 days
E-W Channel	0.024	0.002	0.057	150 days
Slip #3 Containment	0.281	0.0087	0.489	160 days



5-1. Model Framework

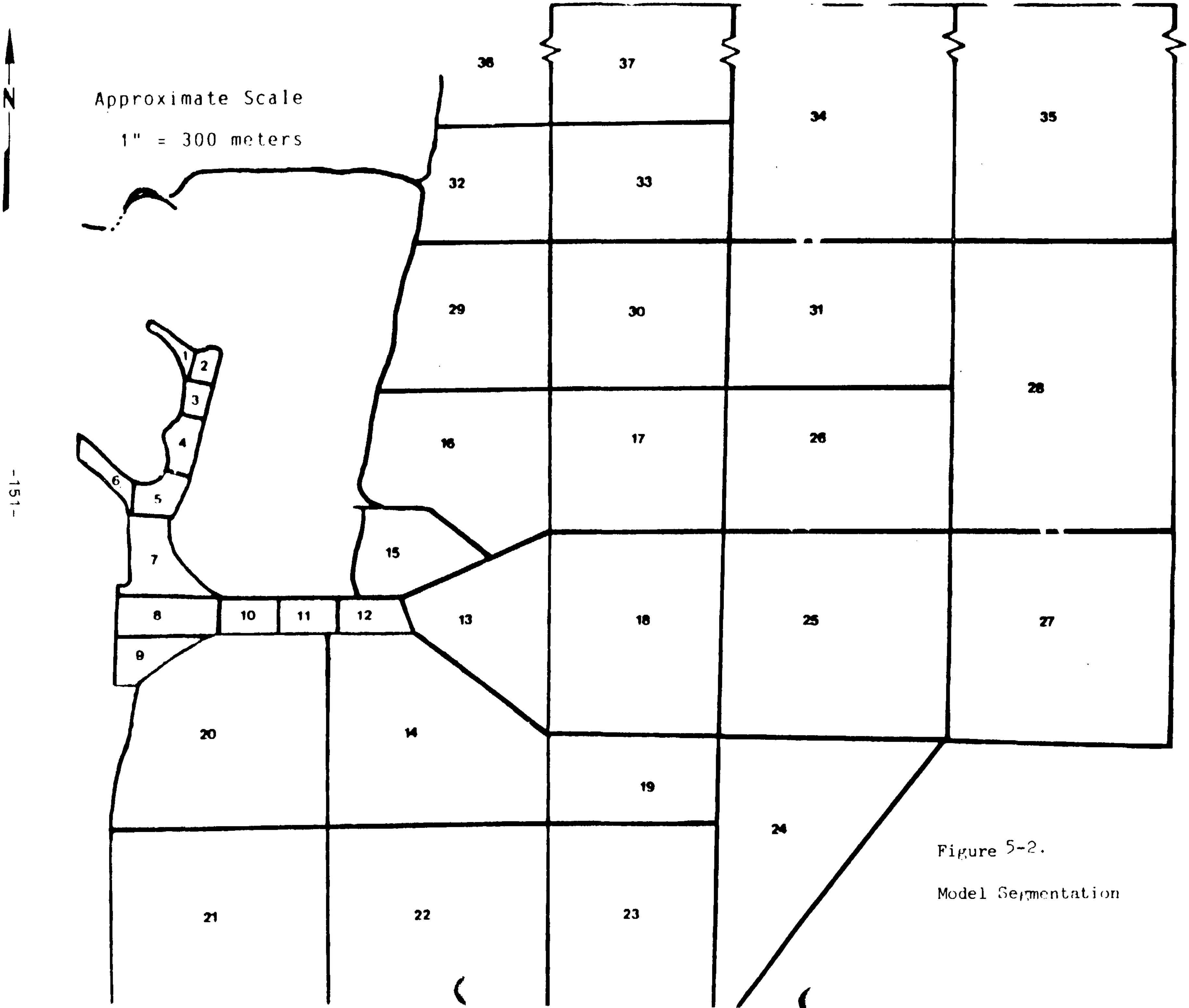


Figure 5-2.

Model Segmentation

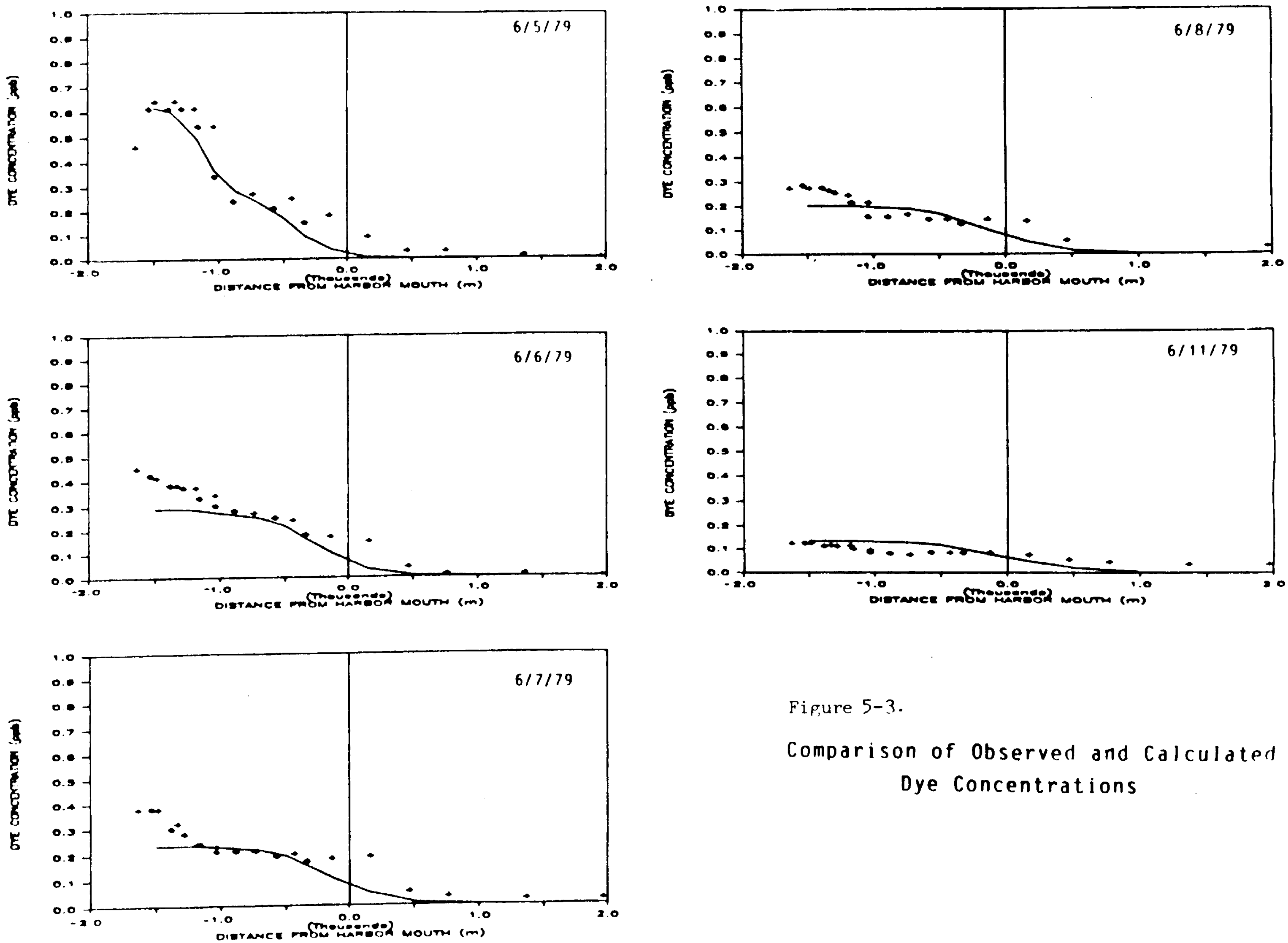


Figure 5-3.

Comparison of Observed and Calculated Dye Concentrations

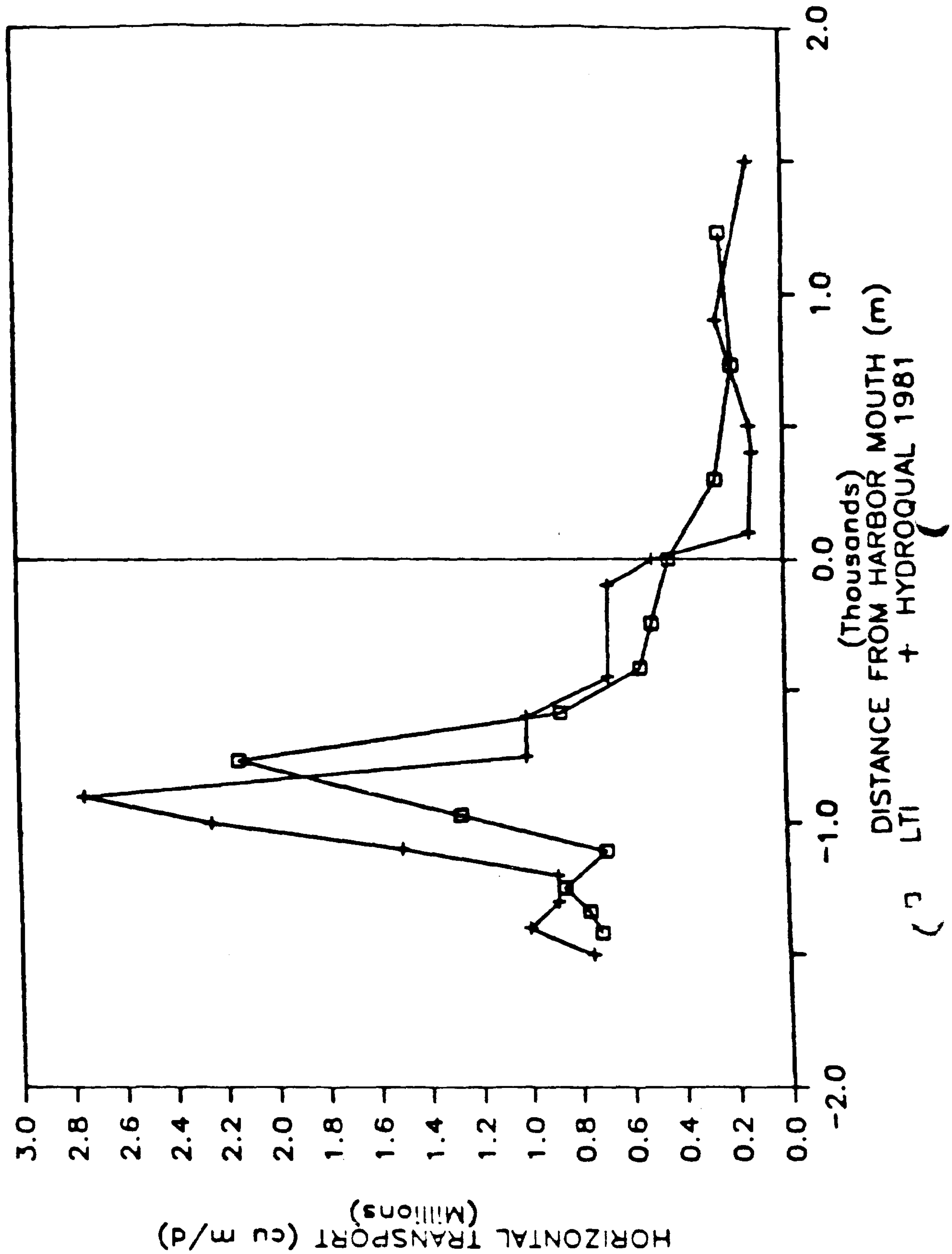


Figure 5-4. Calibrated Horizontal Transport Rates Comparison with Rates Used in Hydroqual Model

Figure 5-5. Comparison of Observed and Calculated Suspended Solids Concentrations

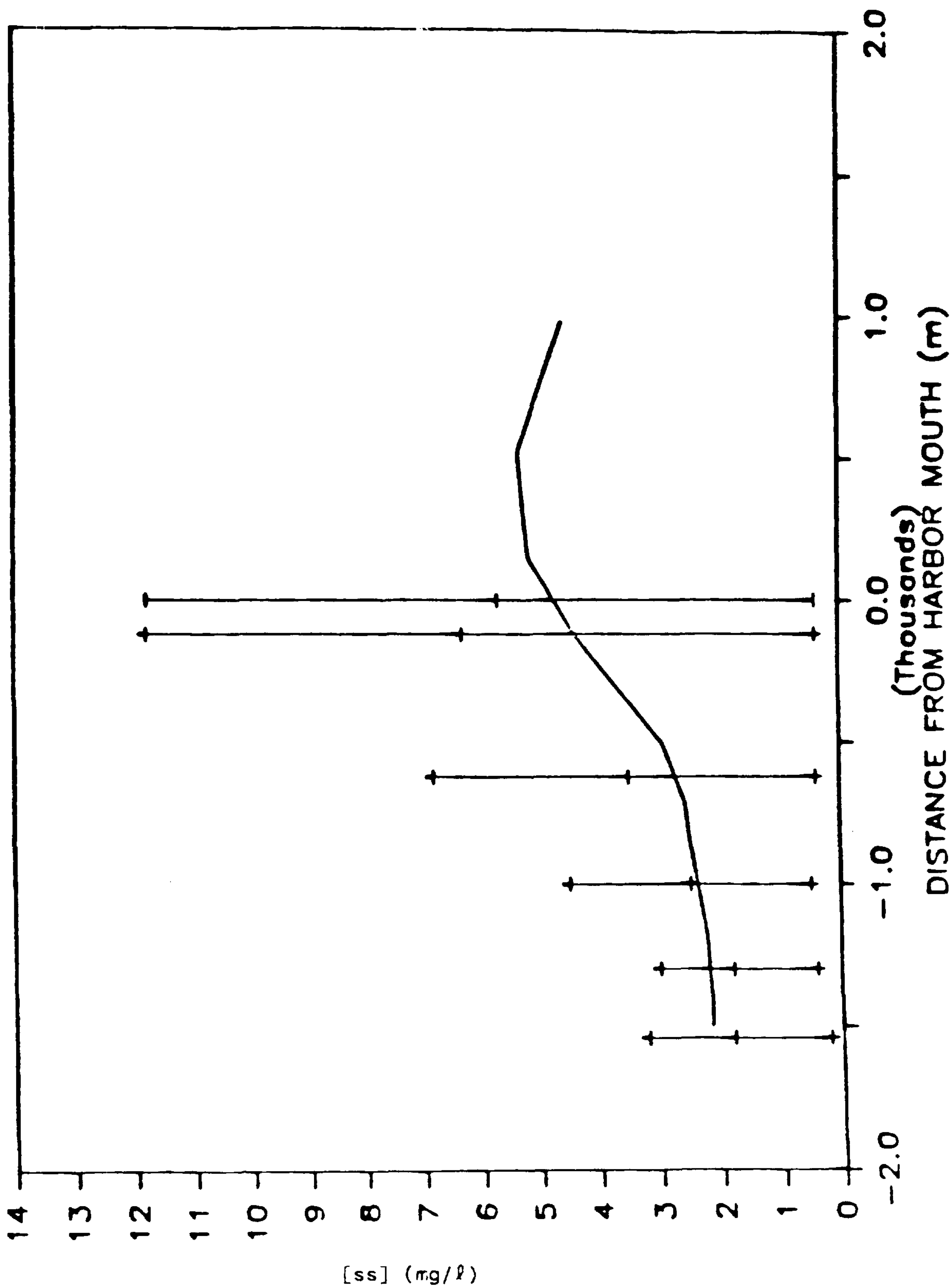
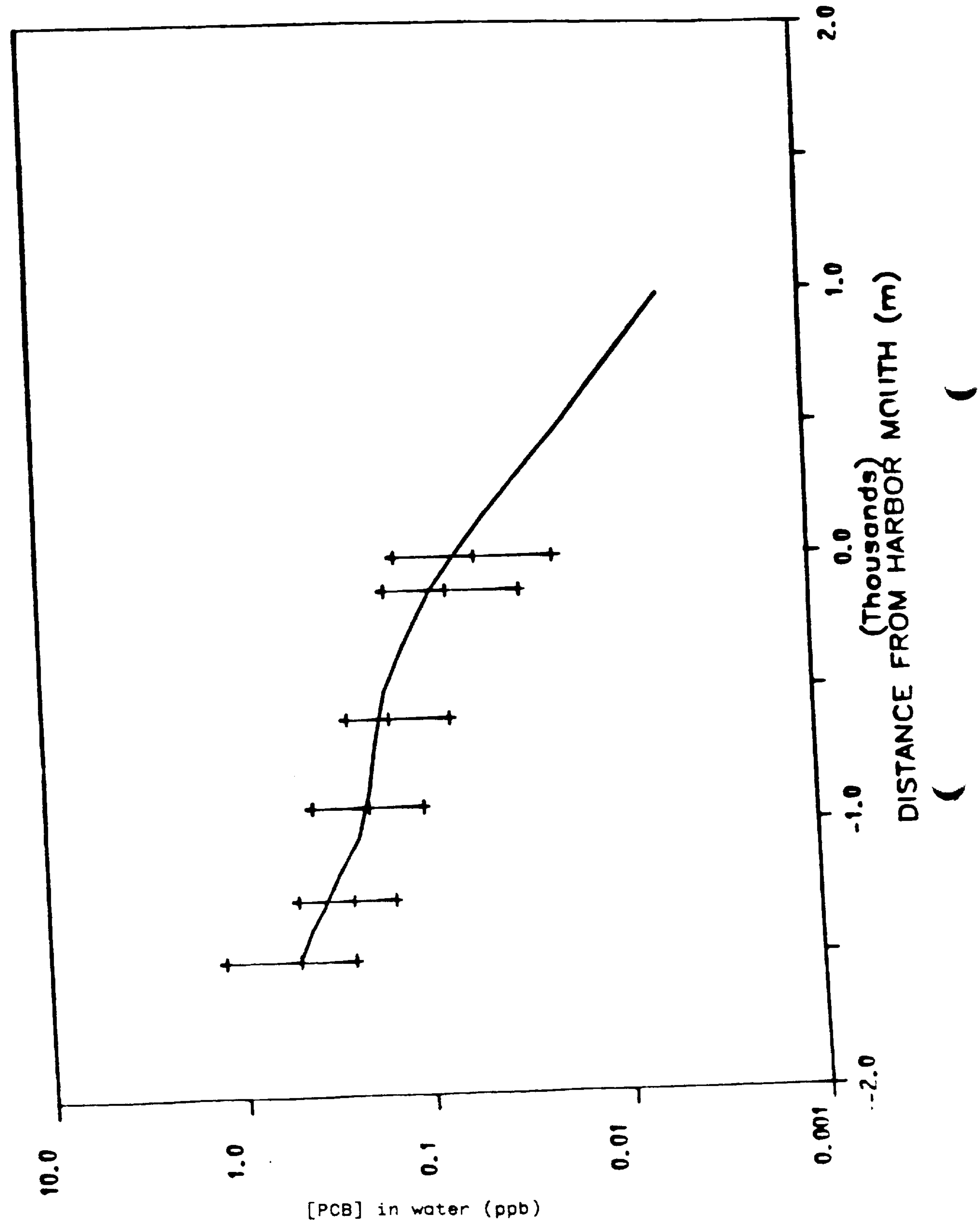


Figure 5-6. Comparison of Observed and Calculated
Total PCB Concentrations



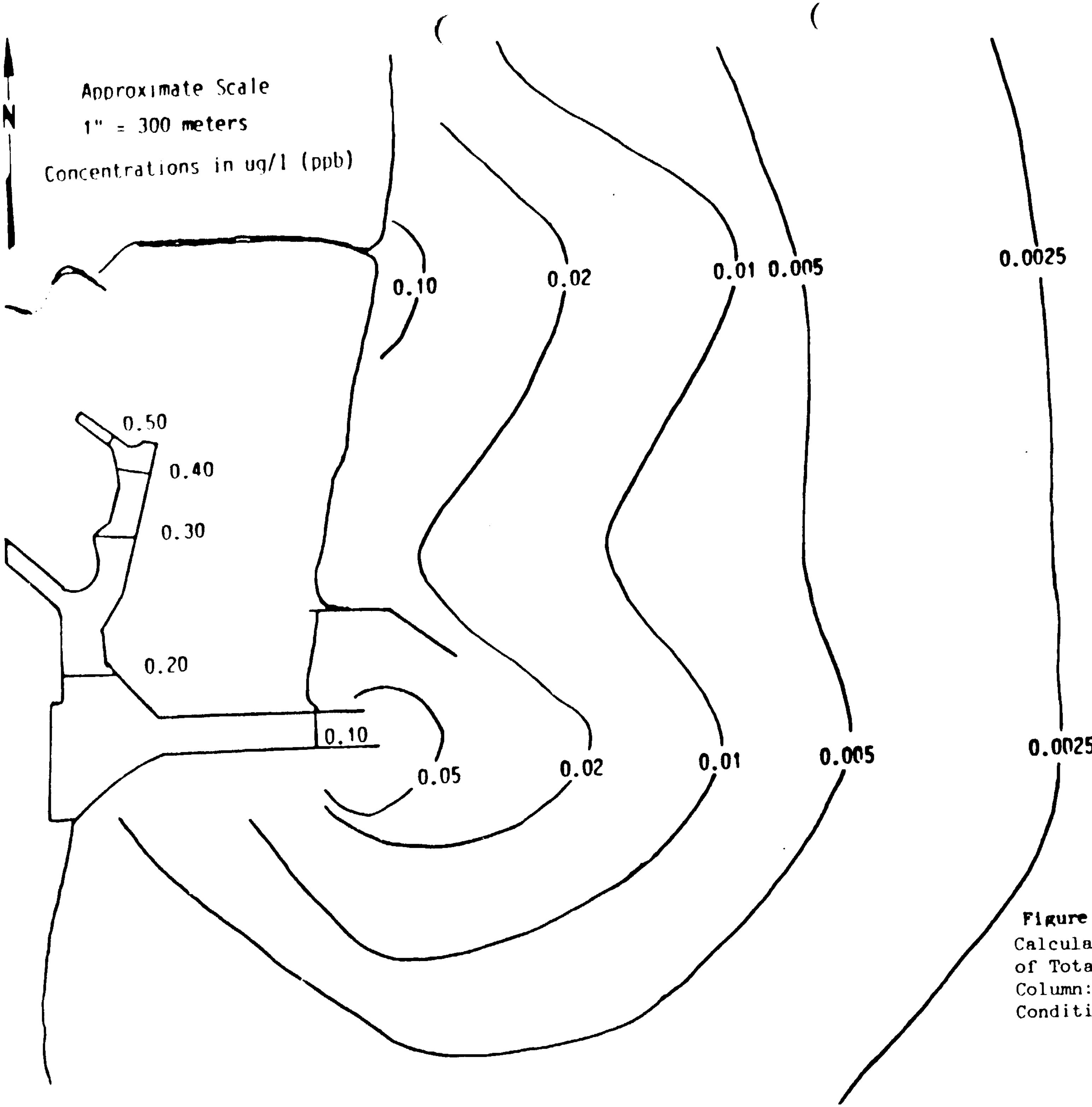


Figure 5-7. Calculated Concentrations of Total PCB in the Water Column: Calibration Conditions

Figure 5-8. Linear Regression Analysis of the Natural Logs of PCB Data for Water in Slip #3 of Waukegan Harbor

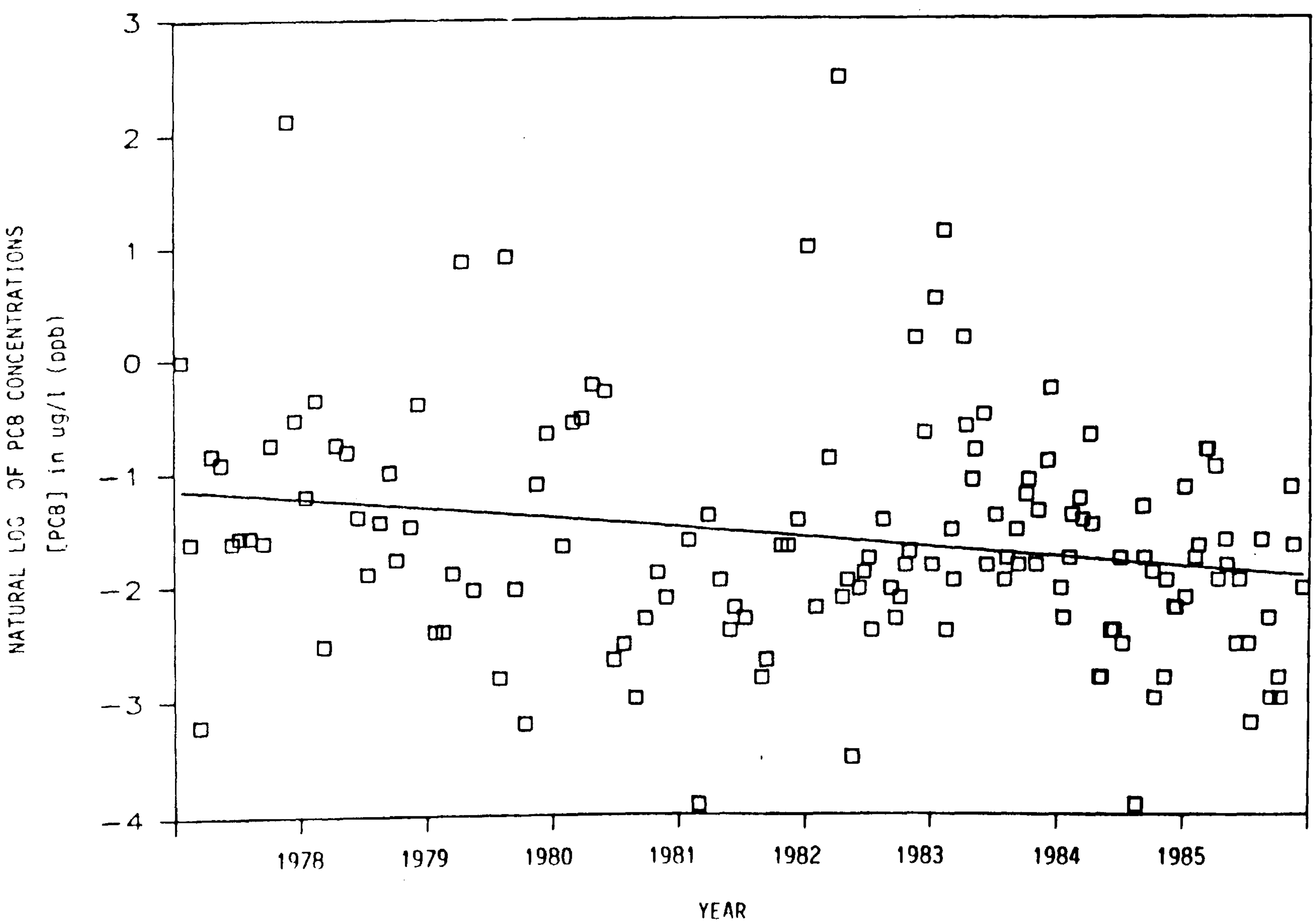


Figure 5-9. Linear Regression Analysis of the Natural Logs of PCB Data for Water in the Upper Harbor of Waukegan Harbor

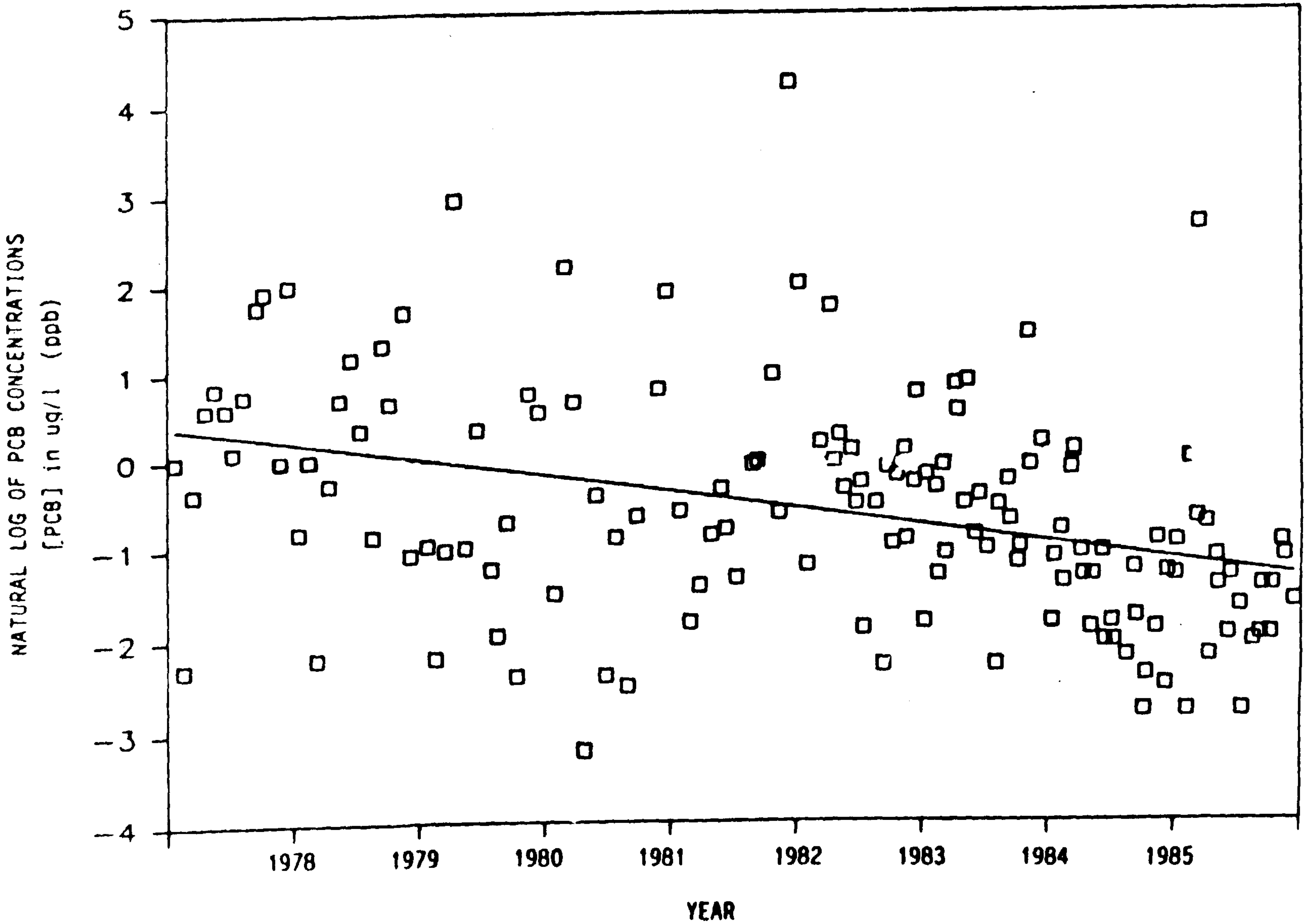
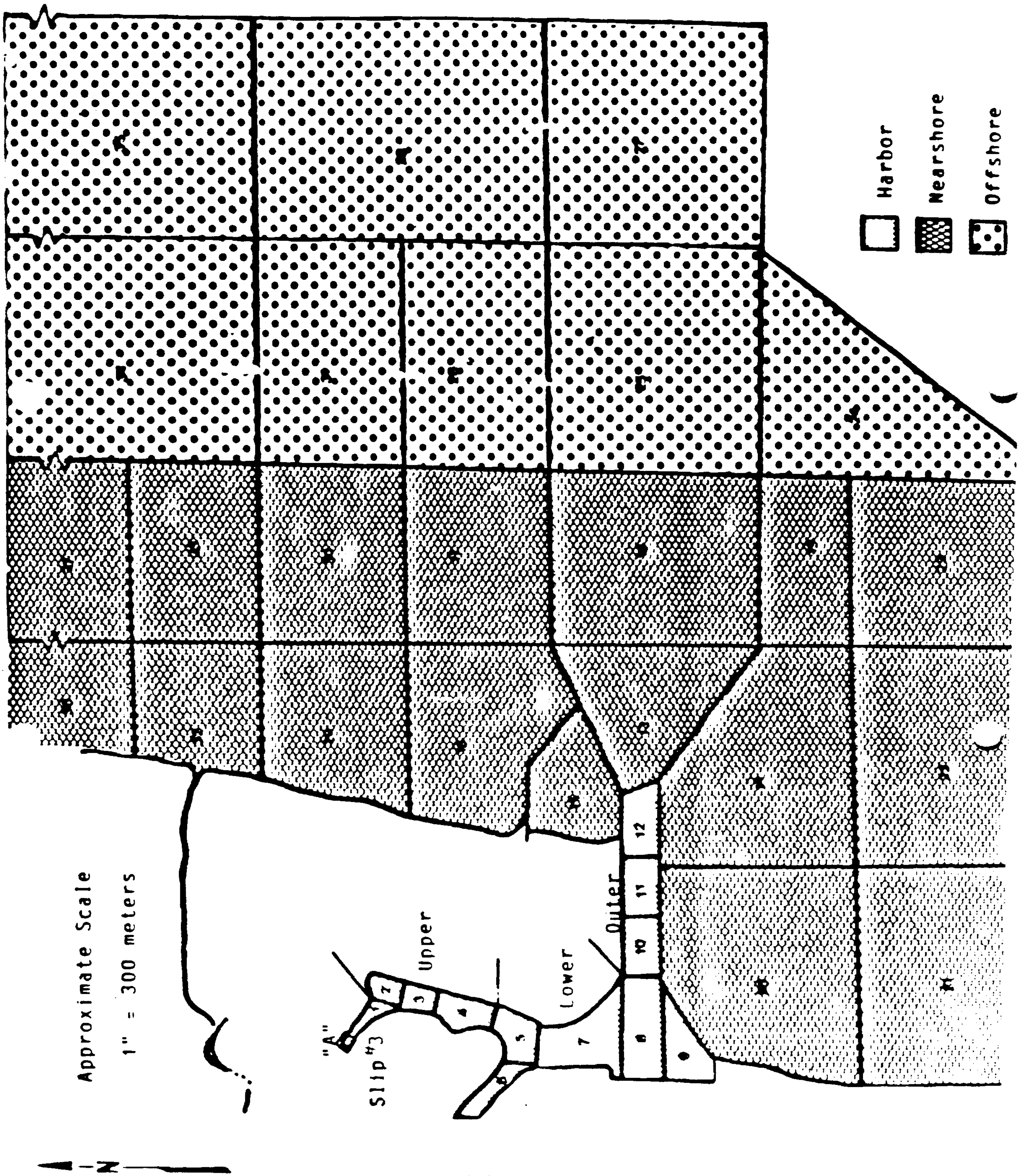


Figure 5-10. Segmentation for Reported Average Model Results



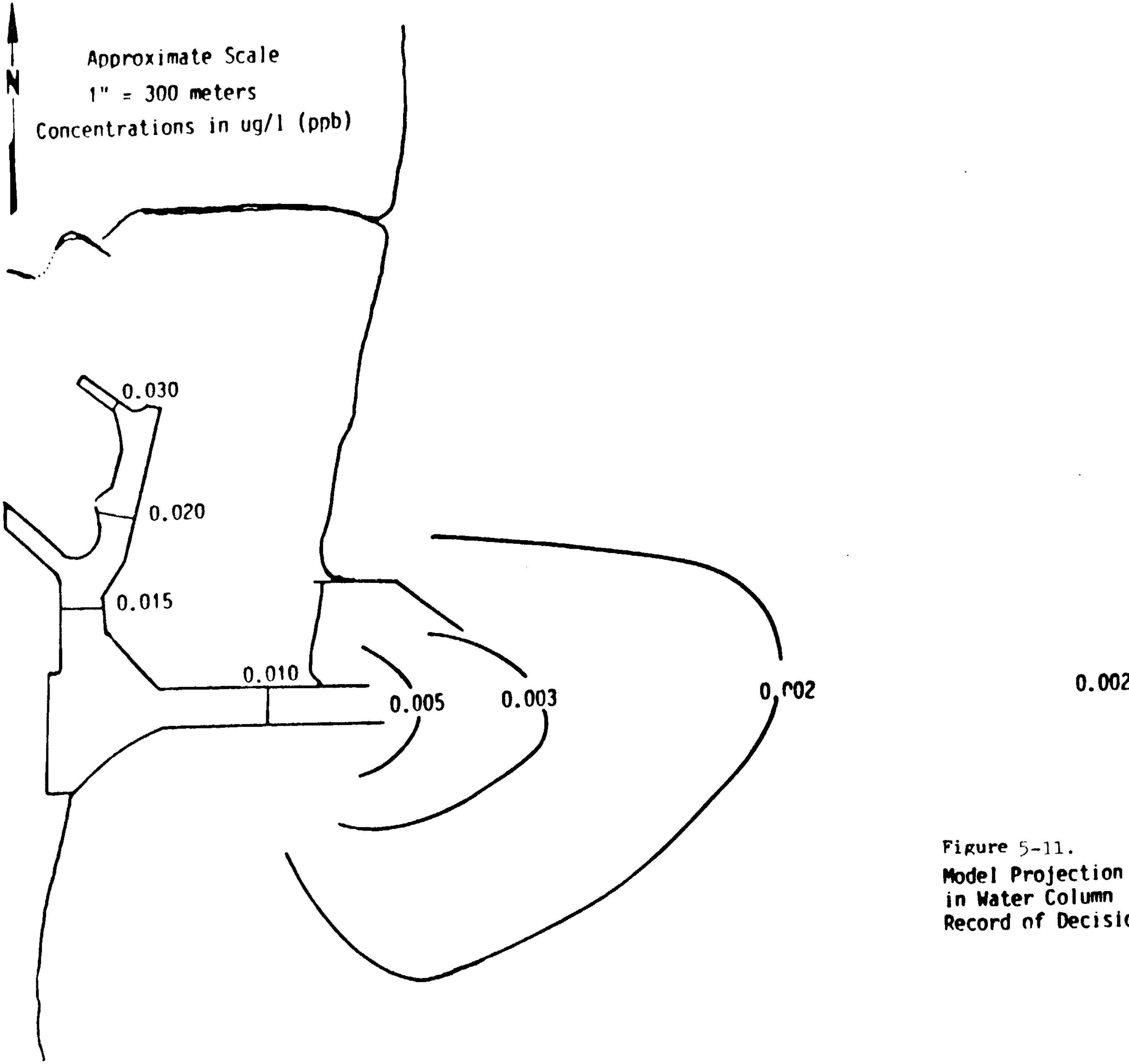


Figure 5-11.
Model Projection of Total PCB in Water Column Record of Decision Alternative

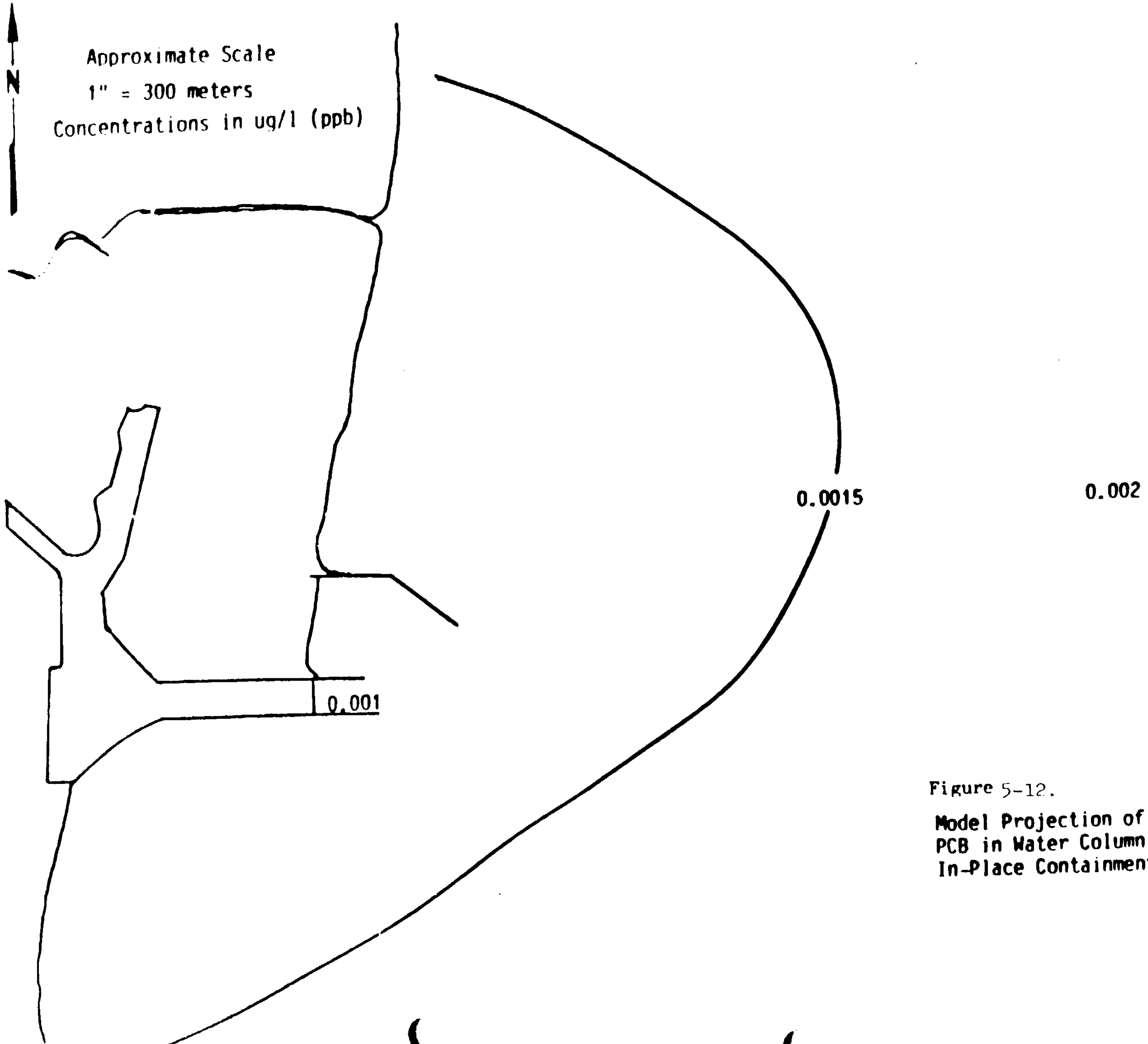


Figure 5-12.
Model Projection of Total PCB in Water Column In-Place Containment Alternative

6. Exposure Assessment

6.1. Introduction

The risk to public health from any chemical depends on two factors: toxicity and degree of exposure. In this chapter, estimates are made of possible exposure to humans through the routes discussed in the EPA Record of Decision (USEPA 1984), including dermal exposure, drinking water, inhalation, and ingestion of contaminated fish.

Two types of exposure estimates are generally provided: "more probable" and "worst case." "More probable" estimates involve midrange values for parameters and are intended to represent best judgments regarding the likely exposures. In this report, the term "worst case analysis" refers to a policy of making assumptions and using procedures that tend to be conservative, that is, that tend in the assessor's judgement to overestimate the risk to humans. In making such estimates, it is always possible to make assumptions that are extremely conservative and also that are extremely unrealistic. Assumptions which some consider to be reasonably conservative may be considered by others to be highly conservative or anti-conservative. By studying the assumptions provided for each exposure route and the indicated consequences of these assumptions, a reader can evaluate for himself the extent to which the worst case analyses discussed here appear to be conservative.

6.2. Exposure Through Inhalation

The population in the vicinity of the OMC site is potentially exposed to PCBs through atmospheric contact. PCBs may volatilize from the PCB in water from the harbor and North Ditch areas and be carried with the air masses over the harbor area and over surrounding residential areas. To estimate the level of PCB exposure from the site, an area-specific flux of PCBs was calculated and the distribution of these PCBs over the Waukegan area was determined using an atmospheric dispersion model.

Estimates of cumulative exposure to residents are calculated assuming a daily respiration rate of 24 cubic meters of air per day (Kimbrough et *al.*, 1984) for 70 years. Exposure estimates for those who work in the vicinity of the harbor are based on as assumed respiration rate of 15 cubic meters of air per eight-hour work day. Cumulative exposure estimates assume that such workers may be employed in this area for 50 weeks per year, for up to 70 years.

6.2.1. Background Concentration of PCBs

Although this report assesses exposures from airborne PCBs originating from the OMC site, it is helpful also to have some indication of what ambient levels of PCBs exist in nearby areas. Researchers have collected air samples from above the Lake Michigan area to determine the background concentration of PCBs. The results show a significant difference between the rural and urban air concentrations. In the rural areas the background concentration is about 1 nanogram per cubic meter (Doskey and Andren, 1981). The same researchers found a range in PCB airborne concentration of 0.8 to 8.07 nanogram per cubic meter in the urban areas. The average PCB concentration in the urban areas was approximately 5 nanograms. Average concentrations were approximately 3 nanograms per cubic meter in Milwaukee and 8 nanograms per cubic meter in Madison and Chicago (Doskey and Andren, 1981). If the parameters discussed in the previous section are applied to these background concentrations, a cumulative, lifetime exposure of 4906 micrograms is estimated for residents of Chicago.

6.2.2. PCB Dispersion Simulation

Estimates of the atmospheric loading of PCBs from the area water bodies are based upon the PCB concentration in the water column and an estimate for the mass transfer coefficient. This loading, presented in Tables 5-12 to 5-14, includes estimates of PCB and volatilization from the harbor, North Ditch areas, containment cells and dewatering lagoons. The distribution of PCBs to the surrounding area is determined using an atmospheric dispersion model which describes the movement of air masses and the volatilized PCBs. The Industrial Source Complex Long Term (ISCLT), Version V, and Short Term (ISCST) atmospheric dispersion models (Bowers *et al.*, 1979) are used to calculate the ground level concentration of the PCBs from the sources using meteorological data representative of the site. These calculated concentrations are compared to background level concentrations found in rural and urban environments around Lake Michigan.

The meteorological data used in the ISC models are from the Zion Nuclear Power Plant site located approximately 10 miles north of Waukegan (Norco, 1986). This site is selected over those from the O'Hare Airport, Milwaukee Airport and Chicago Midway because the coastal Zion site better reflects the microclimatic behavior of the atmosphere that is observed in Waukegan. The coastal zone commonly demonstrates wind direction patterns which are generated by the daily variations in land and lake body temperatures. Inland sites would not demonstrate this microclimatic phenomenon.

The ISC Long Term model employs annualized multiyear data, whereas the ISC Short Term model uses hourly meteorological data. The annualized data represents a joint frequency of wind speed, wind direction and stability class compiled from five years of data collected from the Zion Power Plant site. The extended five year period of data provides a firm basis for the evaluation of a steady-state source. The 1982 Zion Plant site hourly data used in the ISCST simulations have been compared with the available five years of data and were found to represent well the multiyear occurrences of the atmospheric stability classes. Little variability is evident when compared with the five year data (Jirik, 1986a).

The ISC models are steady-state Gaussian plume models for a continuous source. The models provide the downwind concentrations at ground level. The PCB sources are area sources over which atmospheric loadings are distributed. The PCB plume from any point is calculated knowing wind speed and direction, temperature and atmospheric stability category. Atmospheric stability influences the vertical and horizontal dispersion of the plume with distance from the source. The plume dispersion parameters are based on the Pasquill-Gifford curves which are undefined for distances less than 100 meters from the source. This computational restriction influences the PCB concentrations calculated in the near OMC region. For instance, the Larsen Marine site is less than 100 meters from Slip #3. Concentrations calculated for this site may therefore be somewhat low. The effect of this limitation is reduced by dividing the harbor into multiple smaller source regions when applying the air model.

The water bodies with their surface volatilization of PCBs are considered to be area sources for the ISC models. The eleven defined sources, including Slip #3 and the North Ditch, are further divided into 66 discrete areas. The number of model sources for each defined surface body are tabulated in Table 6-1. Each of these model sources is square and has a constant emission rate for each scenario studied. Figure 6-1b displays the OMC site and locations of several sources and discrete receptors.

The steady-state ISC models are reasonably employed since the PCBs are dispersed continuously and over long periods of time relative to air mass dynamics. For short time releases such as found in aspects of the ROD and IPC implementations, the ISCST simulation should provide a more accurate presentation for the PCB concentrations if the correct atmospheric conditions are known. Because accurate conditions are unknown, the ISCLT model is used to predict both long and short term exposures. This approach tends to smooth out short term (e.g., hourly) fluctuations which occur with shifting wind direction and velocity. However, for relative magnitude comparisons, the maximum 24 hour average concentrations are calculated with the ISCST model and are tabulated for selected sites in Table 6-9.

The exposure to PCBs is calculated for the resident population of Waukegan and for specified sites near the PCB sources. The population data is taken from 1980 U.S. Census data. The data describes the resident population's spatial distribution on a city block basis. An investigation of employment figures in the Waukegan area (Jirik, July 17, 1986) revealed three sources of data for employee numbers. The data, however, do not describe where the Waukegan employees work, and of any data which describes worksites, the number which live and work in the city is not provided. Because the spatial location of the transient population (commuting workforce) is not known, site-specific scenarios are used to quantify exposures to persons working in the harbor area.

6.2.3. Atmospheric Concentrations for the ROD and IPC Alternatives

The remedial action proposed by EPA includes the dredging and dewatering of the PCB laden sediment (USEPA, 1984). There will be two dewatering lagoons developed to the east of the upper harbor area, on a site once occupied by the General Motors Foundry. The higher concentrated sediment will be dewatered in lagoon area one, the smaller and assumed more northerly lagoon (see Figure 6-1b). As the water is allowed to evaporate from the lagoon areas, PCBs will volatilize and be dispersed through atmospheric action. The length of time for which the lagoons will be exposed and the PCBs allowed to volatilize is not clear, but model estimates are that they will be in operation for approximately two years. Atmospheric PCB concentrations are calculated for this estimated two year period. The calculated exposure values for the ROD (and the IPC) alternatives are divided into three groups. One is the post cleanup steady-state exposure (Tables 6-3 and 6-6). The value presented here assumes seventy years of exposure to the steady-state PCB concentrations after the ROD (IPC) tasks are complete. During cleanup, PCBs will be exposed to the atmosphere and the increased environmental loading will affect air concentrations for that period of time. However, it is not known when some tasks of the cleanup action may occur. For instance, in the ROD, it is not known when the North Ditch cleanup will begin relative to Slip #3 cleanup. Here it is assumed that these tasks will occur simultaneously. This assumption will have the effect of yielding larger maximum concentrations; however, the cumulative exposure represented in Tables 6-3 through 6-8 still correctly reflects exposure, regardless of task scheduling.

The maximum average daily concentration for each of the seven selected sites is displayed in Table 6-9. These values are calculated with the ISC Short Term model using the one year of hourly meteorological data. The ROD daily values are based on a period of time after the first fifty days of Slip #3 dredging. In fact, it is assumed that atmospheric loadings of PCBs from the slip, upper, lower and outer harbors have been reduced to negligible values. The atmospheric loadings from the North Ditch areas are, however, equivalent to existing conditions, *i.e.*, conditions prior to any remedial action. The significant loadings, and indeed what the calculated concentration reflects, are from the two lagoon sources and the North Ditch containment cell.

Figure 6-1a graphically displays the high concentrations around the dewatering lagoons.

The maximum average daily concentrations for the IPC alternative are based on a period of time, amounting to nearly 45 days, during which the slip and upper harbor are producing atmospheric loads of PCBs greater than those resulting from existing conditions. It is assumed that cleanup action at the North Ditch has not yet begun. The resulting maximum daily concentration at the OMC offices reaches 1.3 micrograms PCB per cubic meter of air, nearly 170 times background levels. It is interesting to note that of the seven identified sites, the twelve largest daily concentrations reached during the year occur at the site of the OMC offices.

The average exposure to the resident population is tabulated in Tables 6-3, 6-4 and 6-5.

6.3. PCB Exposure Due to Ingestion of Fish

Fish are exposed to PCBs through contact with the water, sediments, and smaller organisms that are part of the food chain. The concentration of PCBs in fish tissues is usually much higher than in the surrounding media because fish bioaccumulate PCBs. This section assesses the risk to consumers of fish containing PCBs migrating from the OMC site.

The waters of Lake Michigan near Waukegan appear to be fished rather heavily; it was estimated in Chapter 3 that 634,000 fishermen from Illinois fish in Lake Michigan. Although fisherman use the port facilities in Waukegan Harbor, there is very little fishing activity in the harbor itself. The harbor is small (42 acres) and because it is used for industrial purposes, it is not conducive to fishing. EPA's difficulties in obtaining fish samples from the harbor (Chapter 3) suggest that there are very few sport fish in the harbor. According to the EPA Record of Decision Briefing Material, "No Fishing" signs are posted in the harbor. Accordingly, this section will focus primarily on the risk from eating Lake Michigan fish containing PCBs originating from the area of the upper harbor.

Assessing risk from PCBs from the harbor is a complex problem because PCBs have entered the lake from many sources and it is difficult to measure OMC's contribution to the total PCB levels. According to the analysis in Chapter 5, the lake area impacted by PCBs from OMC is small (on the order of one mile in radius). It would be useful to know the number of persons fishing in this area, the total amount of fish caught, and the fraction of total fish caught at various distances from the harbor mouth. Currently, reliable data are not available for these variables and extensive data gathering and sampling would be required to fill these data gaps. Similar data are available for Lake Michigan as a whole, but this is not the data needed to estimate exposures due to contributions from the upper harbor area.

In view of the limitations of fish survey data, an assessment of exposure has been based on well-defined scenarios regarding fishing patterns and fish consumption. PCB levels in fish are estimated by applying a bioaccumulation factor to estimated levels of PCBs in water that are calculated in Chapter 5 and taking into account the percent of time fish spend in areas similar to that impacted by the OMC site.

Estimates of levels of contamination in fish caught in and adjacent to Waukegan Harbor are used to estimate exposure to those who consume these fish. Estimates of exposure are calculated for a single-day, in order to estimate risk of non-carcinogenic effects, and for an average lifetime, in order to estimate carcinogenic risks.

6.3.1. Assumptions

The amount of PCBs from Waukegan Harbor in Lake Michigan water is related to distance from the harbor (cf. Figures 5-11 and 5-12). Therefore, assumptions are necessary concerning the waters that fish inhabit. For single-day exposure estimates, fish that are consumed are assumed to have been exposed for 10% of the time to ambient conditions consistent with the nearshore area and 10% of the time to conditions consistent with the offshore area (more probable estimate). For worst case single-day exposure estimates, it is assumed that fish consumed are caught from the harbor and are contaminated at levels observed in sport fish taken from the harbor. For total exposure estimates, it is assumed that the fish consumed have been exposed to ambient conditions in the nearshore in close proximity to Waukegan Harbor for approximately 10% of the time, to conditions in the adjacent offshore area for 10% of the time, and to conditions in the main body of the lake for 80% of the time, as discussed in Chapter 5. Although these assumptions reflect observed migration of fish in different depth zones of the lake, they are extremely conservative in that they do not fully take into account the broader migratory patterns of fish. These sport fish migrate in directions parallel as well as perpendicular to the shore and are only impacted by Waukegan Harbor for a small portion of the time spent in the nearshore area. The applicable nearshore and offshore areas are identified in Figure 5-10. That portion of the lake beyond the offshore area will be considered as the main body of the lake for this assessment.

Based on information in Chapter 3, fish consumption is estimated to be 0.224 kg (8 ounces) for a single-day exposure, and for total exposure 3.41 kg per year (more probable estimate) or 21.4 kg per year (worst case estimate). Measurements of PCB levels in raw and cooked fish indicate substantial losses from preparation and cooking. A conservative estimate of this reduction has been chosen by assuming that PCB concentrations in fish will be reduced through cooking by a factor of 1.65 (Chapter 3). Other sources of data suggest that cooking may reduce PCB levels by as much as 75% (FDA, 1979) to 80% (Maxim and Harrington, 1984).

In order to estimate a lifetime exposure to PCBs, it is assumed that fish are consumed at the previously stated rate for 30 years (more reasonable) or 60 years (worst case). It is also assumed that all the fish consumed during these lengthy periods spend 20% of the time in the small nearshore and offshore areas identified in Figure 5-10. This appears to be a highly conservative assumption since it is unlikely that a person's fish consumption for an entire lifetime would come from the small area of Lake Michigan affected by Waukegan Harbor.

PCB concentrations in raw fish were determined by subtracting the background levels of PCBs in the fish from levels of PCBs in fish calculated for each clean-up alternative (see Table 5-7). These alternatives include the Record of Decision alternative (ROD) and the

In-Place Containment alternative (IPC), which are discussed in detail in Chapter 4. Levels of PCBs in fish from the harbor have been estimated by utilizing both experimental and theoretical data. The data are limited because, in studies to determine PCBs in Lake Michigan fish, very few sport fish have been caught in Waukegan Harbor (Chapter 3). Those caught and analyzed include one rainbow trout and eight yellow perch, captured in 1980 and 1981. Actual measurements of PCBs in tissues of these sport fish caught from the harbor show a range of 1.41 to 34.0 ppm. The upper limit of these measurements represents only 18% of the levels predicted from environmental modeling of existing conditions. Therefore, values predicted for fish from the harbor for the ROD and IPC alternatives have been adjusted downward by the same ratio (18% of value predicted by modeling, as listed in Table 5-6).

PCB concentrations in cooked fish were then estimated by reducing the values for raw fish by a factor of 1.65; the resulting concentrations are given in Table 6-10.

6.3.2. Estimating Exposure for Steady-State Alternatives

Single-day more probable estimates of exposure are estimated from the formula

$$(0.224 \text{ kg})(C_n + C_o \text{ mg/kg})(1000 \ \mu\text{g/mg}) = 224 * (C_n + C_o)\mu\text{g},$$

where C_n = PCB concentrations (best estimate) in cooked fish exposed to ambient conditions consistent with nearshore levels of PCBs, and C_o = PCB concentrations (best estimate) in cooked fish exposed to ambient conditions consistent with offshore levels of PCBs.

Single-day worst case estimates are calculated as

$$(0.224\ \text{kg})(C_h\ \text{mg/kg})(1000\ \mu\text{g/mg}) = 224 * C_h\ \mu\text{g},$$

where C_h represents PCB concentrations (maximum) in cooked fish exposed to ambient conditions consistent with levels of PCBs found in Waukegan Harbor. Values of C_h are taken from Table 6-10.

More probable estimates of total exposure are obtained from the formula

$$(3.41\ \text{kg/yr})(C_n + C_o\ \text{mg/kg})(1000\ \mu\text{g/mg})(30\ \text{yrs}) = 1.02\text{x}10^5 * (C_n + C_o)\ \mu\text{g},$$

where C_n and C_o represent PCB concentrations (best estimate) in cooked fish as previously defined and where it is being assumed that the impact of PCBs from the Waukegan site is confined to the nearshore and offshore areas depicted in Figure 5-10.

Worst case estimates of total exposure are obtained from the formula

$$(21.4\ \text{kg/yr})(C_n + C_o\ \text{mg/kg})(1000\ \mu\text{g/mg})(60\ \text{yr}) = 1.28\text{x}10^6 * (C_n + C_o)\ \mu\text{g}.$$

where here C_n and C_o represent concentrations (maximum) in cooked fish as previously defined. Estimates of exposure by ingestion of fish are summarized in Table 6-11.

6.4. Exposure by Dermal Contact

Exposure through dermal contact could occur in numerous activities. The EPA Record of Decision discusses the possibility of exposure at the public beach located on Lake Michigan to the east of the upper part of Waukegan Harbor and through washing PCB-containing mud or silt from boats. Dermal exposures are likely to vary considerably depending upon the level of PCBs in the sediments and the type of activity and would be difficult to estimate accurately. To evaluate the possible exposure through this route a scenario is developed based upon the washing of boats. The results of dermal exposure estimates for the two different remedial alternatives described in Chapter 4 are summarized in Table 6-12.

PCB harbor concentrations are generally highest in Slip #3 and decrease progressively toward the harbor area south of Slip #3. According to the USEPA briefing material on the OMC Remedial Action, Larsen Marine Service, Inc. is located at Slip #3 and provides complete marine repair services and performs removal and storage of boats using a crane operated hoist. The segment of Slip #3 in the vicinity of Larsen Marine has been found to contain sediments averaging 1737 ppm PCB (Figure 4-1). Sediments from the lower harbor, where the boat launching facilities are located, show PCB levels less than 20 ppm. Surface sediments at different locations in the Waukegan Harbor have been identified as containing Aroclors 1242 and 1248 only (Armstrong, 1980). In the Slip #3 region, Aroclor 1242 was found to be the major component with a gradual shift to a predominance of Aroclor 1248 as one proceeded towards the harbor mouth.

6.4.1. EPA Record of Decision (ROD) Alternative

According to the remedial alternative envisioned in the EPA Record of Decision, the upper harbor is to be dredged to remove sediments containing PCBs greater than 50 ppm while silt and sediments in Slip #3 will be excavated and disposed of in an offsite landfill. In Chapter 5 it was pointed out that it is difficult for dredging operations to achieve an efficiency higher than 90% in removing sediments containing PCBs. Hence, it will be assumed that this remedial alternative reduces the PCB level only to about one tenth of the original concentration in Slip #3. This would imply that the sediments in the neighborhood of the Larsen Marine might contain about 174 ppm of PCB even after the remedial action has been taken.

6.4.1.1. Worst case estimate for a single boat wash: ROD Alternative

For the worst case situation, let us assume that a person washing the mud and silt off a boat is exposed to sediments containing an average PCB level of 174 ppm.

For an adult human whose body weight is 55 kg, the total body surface area is about 1.61 m^2 (Hawley, 1984). If we suppose that a person is clothed in shorts for the washing chores, approximately 80% of the body surface may be exposed, that is,

$$1.61 \text{ m}^2 \times 0.80 = 1.29 \text{ m}^2.$$

It is difficult to estimate the amount of mud or silt that might come in contact with a person's skin in such an activity. Kimbrough *et al.* (1984) made plausible estimates of daily deposition of soil on exposed skin for different age groups. These values indicated that maximum amount of soil deposition takes place for the 1.5 year to 3.5 year age group. Lepow *et al.* (1975) investigated ingestion of lead among urban preschool children at play around the dwellings where they lived. Their studies showed that the average weight of dirt on a 21.5 cm^2 area of a child's hand was 11 mg. In estimating the amount of mud or dirt to which a person may be exposed while cleaning a boat, it is likely that the person will use some kind of a brush or a scraper while hosing down the debris, thereby reducing the chances of direct contact with soil. If we use the Lepow value as an upper bound to the rate of soil deposition during cleaning, the total weight of dirt on the exposed body surface will at most be equal to

$$(1.29\text{m}^2)(10^4 \text{ cm}^2/\text{m}^2)(11 \text{ mg}/21.5 \text{ cm}^2)(1 \text{ g}/10^3 \text{ mg}) = 6.60 \text{ g}.$$

This quantity of mud contains (using 1737 ppm for the PCB level)

$$(6.60 \text{ g})(10^3 \text{ mg/g})(174\times10^{-6}) = 1.15 \text{ mg PCB}.$$

Wester *et al*. (1983) found that post-contact washing cannot be assumed to remove all applied PCB from the skin, as only about half (58.9% with a standard deviation of 7.5%) of [^{14}C]-labeled 42% PCB could be recovered in their experiments with guinea pigs. We will, as a worst case, presume that, even if a person bathes after washing the boat, he is still potentially exposed to the chemical to the extent of about 1.15 mg.

A chemical mixed in a soil medium could possibly be inhibited in its penetration of the skin due to a small portion of the substance being available for skin contact and also due to physical and chemical bonding (adsorption) of the compound to the matrix (this is particularly true for smaller silt-like organic soil particles). Hawley (1984) estimated that the soil matrix had the effect of reducing the dermal absorption rate for the direct application of tetrachlorodibenzodioxin (TCDD) to 15%. Since the processes of adsorption and removal of PCBs by biological and chemical means are not yet fully understood, we will not take the matrix effect into account in estimating the worst case PCB exposure.

Data compiled by Wester and Maibach (1976) on the percutaneous absorption of hydrocortisone, testosterone, and benzoic acid showed that the absorption characteristics of the rhesus monkey were close to those of man. Similar results were also found by Maibach and Wolfram (1981) in the percutaneous absorption of hair dyes in the rhesus monkey and man. Studies of dermal absorption of PCBs by Wester *et al* (1983) yielded absorption rates of 15% to 34% in rhesus monkeys for [^{14}C]-labeled 42% PCB. For our worst case scenario, we will assume a maximum dermal absorption of 100%, *i.e.*, 1.15 mg of PCB per boat wash.

For a single washing of a boat covered with sediments containing 174 ppm of PCB, the maximum single-day exposure can therefore be estimated as

$$(1.15\ mg)(10^3\ \mu g/mg) = 1,150\ \mu g.$$

Assuming a human weight of 55 kg, the maximum single-day exposure is given by

$$1,150\ \mu g\ /\ 55\ kg = 20.9\ \mu g\ /\ kg.$$

The above calculation is for a worst case single-day exposure and is based on the following hypotheses:

a. The average weight of an adult human is 55 kg.

b. The average surface area of a human body is 1.61 m^2.

c. The average exposed area during cleaning is 80% of total area.

d. The average concentration of soil on the exposed portion of a person's body during cleaning is equal to that on the hands of a small child from playing outdoors, namely 0.51 mg/cm^2.

e. The dermal absorption rate is 100%.

f. The ROD remedial alternative is only 90% effective in reducing the PCB level in the Slip #3 and the upper harbor area.

g. The level of exposure is equivalent to dermal contact with soil sediments containing 174 ppm PCB.

6.4.1.2. A More Probable Case for a Single Boat Wash: ROD Alternative

As the boat launching ramps at the harbor are more than 600 meters away from Slip #3, most of the recreational boating would likely occur in the part of the harbor where the PCB levels of the sediment may be assumed to equal the average value of 16.5 ppm found near the Waukegan Port District. The proposed dredging of the harbor is expected to remove only sediments with PCB content of more than 50 ppm and, consequently, we may presume that the remedial action will not in any way adversely affect the average concentrations (less than 20 ppm) in the lower harbor. Further, the plausible rate of dermal absorption of PCB through human skin could be approximated by the maximum absorption rate found in the rhesus monkeys, *i.e.*, 34%.

With these modifications, a single-day exposure assessment for the more probable case can be obtained as follows:

Amount of PCB exposure for a person washing a boat on a single-day

$$= (6.60\ \text{g})(10^6\ \mu\text{g/g})(16.5\times10^{-6})(0.34) = 37\ \mu\text{g}.$$

For an average adult of 55 kg weight, this corresponds to a single day exposure of 0.673 μg/kg.

6.4.1.3. Multiple Boat Washings: ROD Alternative

In the absence of conclusive information on the degradation properties of PCB in soil sediments, lifetime exposure evaluations for multiple boat washings over a period of years are obtained under the assumption that the PCB concentration levels in the sediments remain essentially the same.

Let us assume that a person, during his lifetime, may wash boats for 20 years, each year at the end of the season on removal from water for storage. It may be recalled (Section 6.4.1) that the maximum worst case single-day exposure was obtained using a value of 174 ppm as the PCB content for the sediment near the Larsen Marine area. A plausible worst case situation for multiple washings over a long period of time is assumed to be one in which the soil being washed from the boat contains 174 ppm PCB (a high value) for one wash, but has 16.5 ppm (the average value at the lower harbor area) for the other washes. Under these assumptions, the total quantity of the PCBs that a person is exposed to in twenty years amounts to

$$(1{,}150\ \mu g/wash)(1\ wash) + (37\ \mu g/wash)(1\ wash/yr)(19yr) = 1{,}853\ \mu g.$$

The worst case average daily exposure for a lifetime is

$$(1{,}853\ \mu g/55\ kg)/(25{,}550\ days) = 1.32 \times 10^{-3}\ \mu g/kg/day,$$

where the average life span of an human is estimated to be 70 years or 70 x 365 = 25,550 days.

For a more probable case, the extent of PCB exposure due to twenty years of boat washing may be conservatively estimated as twenty times the single-day exposure obtained in Section 6.4.1.2, giving

$$(37\ \mu g/wash)(1\ wash/yr)(20\ yr) = 740\ \mu g.$$

This value averaged over 70 years (25,550 days) now yields a lifetime average daily exposure as

$$(740\ \mu g/55\ kg)/25{,}550\ days = 5.27\times10^{-4}\ \mu g/kg/day.$$

6.4.2. In-Place Containment (IPC) Alternative

This alternative action, as described in Chapter 4, proposes to contain all PCB laden sediments on-sit in a containment cell built across the mouth of Slip #3 and to dredge and deposit in this cell sediments with PCB greater than 50 ppm. Assuming again that the efficiency of dredging is at best 90%, the upper harbor will have sediments with PCB content of not more than 55 ppm. The lower harbor may be presumed to be unaffected by this operation. These assumptions will form the basis for the following exposure estimates.

6.4.2.1. Worst Case Estimate for a Single Boat Wash: IPC Alternative

Here, the estimate of PCB exposure is arrived at by replacing the value of 174 ppm from the ROD alternative (Section 6.4.1.1) by 55 ppm, and we get the maximum single-day exposure to be 364 μg.

6.4.2.2. A More Probable Case for a Single Boat Wash: IPC Alternative

Since the lower harbor is assumed to be unaffected by the IPC operation, the maximum exposure estimate is the same as that for the ROD (Section 6.4.1.2), namely, 37 μg of PCB per wash which is equivalent to

0.673 μg/kg.

6.4.2.3. Multiple Boat Washings: IPC Alternative

The exposure estimates for multiple washings are calculated analogous to that made in Section 6.4.1.3. For the worst case analysis we assume that a person is exposed to 364 μg of PCB (Section 6.4.2.1) for one wash while for the other 19 washes the exposure is considered to be about 37 μg (Section 6.4.2.2). On the other hand, for the more probable case, the exposure amounts are presumed to be 37 μg for each of the 20 washes. For the worst case, the extent of total lifetime exposure is

$$(364\ \mu g/wash)(1\ wash) + (37\ \mu g/wash)(1\ wash/yr)(19\ yr) = 1{,}067\ \mu g$$

or a lifetime average daily exposure of 7.59×10^{-4} μg/kg/day.

For the more probable case, the total exposure is 740 μg, which translates to a lifetime average daily exposure of 5.27×10^{-4} μg/kg/day.

6.5. Exposure by Drinking Water

The exposures to PCB due to drinking water from the Waukegan Water Supply System are computed on the assumptions that

(a) the water supply system will continue to use the emergency water intake situated in the lower harbor at times of need, and that

(b) a person drinks on an average two liters of water per day.

6.5.1. PCB Concentrations in Water

The levels of PCB in the surface water in the Waukegan harbor are much lower than those in the sediments. Water samples obtained from different locations in the harbor area (Versar, 1980) showed higher concentrations of PCB at the west end of Slip #3, the level decreasing as one proceeds towards the mouth of the harbor. PCB levels in the upper harbor area were in the range from 0.21 to 14 ppb (averaging about 2.7 ppb) while the corresponding range for the harbor inlet region was from less than 0.01 to 0.31 ppb (average about 0.14 ppb). Harbor intakes at the OMC Johnson facility have been monitored at two locations, HI-1 and HI-2, for the period from Jananuary, 1977 to Dececember, 1985. HI-2 is located in Slip #3, approximately a third of the distance from the west end, while HI-1 intake is at the lower harbor area, near Johnson Motors Plant #1. A review of the intakes at HI-2 revealed that the mean PCB levels over each twelve month period from January 1977 until December, 1985 decreased from about 2.64 $\mu g/\ell$ (2.64 ppb) to about 0.9 $\mu g/\ell$ (0.9 ppb), although high anomalous values (19 ppb and 68 ppb) were also observed. PCB levels monitored at HI-1 exhibited similar characteristics: the monthly averages decreased from 1.03 $\mu g/\ell$ (1.03 ppb) to 0.12 $\mu g/\ell$ (0.12 ppb), while occasional values as high as 8 and 12 ppb were reported.

6.5.2. PCB Exposure Due to Drinking Water

The City of Waukegan maintains an emergency drinking water intake in Waukegan Harbor. This intake has been sparingly used but is an integral part of the Waukegan water supply. Should the city need to utilize the emergency intake, PCBs from the harbor would be introduced into the drinking water system. According to the emergency water use information provided by the Outboard Marine Corporation (OMC), the City of Waukegan operated the emergency water intake for a total 87.5 hours during the period from February, 1968 to January, 1978, which averages to 8.75 hours per year. We will therefore assume that a person using drinking water from this system will be exposed to PCBs an average of 8.75 hours per year during his lifetime of 70 years; this is equivalent to exposure for

$$(8.75 \text{ hours/yr})(70 \text{ yr})/(24 \text{ hours/day}) = 25.5 \text{ days}.$$

The average daily consumption of water by a human is estimated to be about 2 liters. A person drinking 2 liters of water daily from the Waukegan water supply system over a lifetime of 70 years, will consume the water to the extent of $(2\ \ell/\text{day})(25.5\text{days}) = 51$ liters.

Steady-state projections of PCB levels in water for the various regions of the harbor under the two clean up alternatives are set out in Table 5-4. The maximum values therein will be used for worst case analyses while the best estimates will provide the basis for the more probable case. Exposure estimates are computed using these values corrected for the background by subtracting the PCB levels (Table 5-3) that provide base case concentrations in the absence of PCBs in the harbor area from the observed levels in the water column. In the following sections, values are computed for the drinking water exposure under each of the alternatives and are displayed in Table 6-13.

6.5.2.1. EPA Record of Decision (ROD) Alternative

For the ROD alternative action, the maximum PCB level in the harbor waters corrected for background levels is 0.0263 ppb obtained by subtracting the base concentration level of 0.0007 ppb (Table 5-3) from the estimated value of 0.027 ppb (Table 5-4). This value will provide the worst case estimate of exposure by drinking water. For the more probable case, however, we shall use the best estimate of 0.0133 ppb obtained from Table 5-4 after subtracting the background concentration level of 0.0007 ppb. The computations for the two cases follow in the next two subsections.

6.5.2.1.1. Worst Case Estimate: ROD Alternative

We shall assume that the water from the Waukegan water supply contains 0.0263 ppb PCB and that a person drinks 2 liters of water per day from the Waukegan water supply. This would correspond to a maximum single-day exposure of

$$(2\ \ell)(10^9\ \mu g/\ell)(0.0263 \times 10^{-9}) = 0.0526\ \mu g.$$

If the total amount of water (containing PCBs) ingested during an average lifetime is estimated (Section 6.5.2) as 51 liters, the amount of PCB is

$$(51\ \ell)(10^9\ \mu g/\ell)(0.0263 \times 10^{-9}) = 1.34\ \mu g.$$

The equivalent average daily exposure over a lifetime of 70 years (25,550 days) is then obtained as

$$1.34\ \mu g/(55\ kg \times 25{,}550\ days) = 9.54 \times 10^{-7}\ \mu g/kg/day.$$

6.5.2.1.2. More Probable Case: ROD Alternative

If we use the best estimate of 0.0133 ppb (Tables 5-3 and 5-4), the maximum single-day exposure is given by 0.0266 μg. The total lifetime exposure becomes 0.678 μg and the average daily intake for a lifetime is 4.83×10^{-7} μg.

6.5.2.2. In-Place Containment (IPC) Alternative

The computations for the drinking water exposures for the IPC alternative follow along the same lines as for the ROD above.

6.5.2.2.1. Worst Case: IPC Alternative

Here, the maximum level of PCB in water (corrected for base concentration) is estimated to be 0.0036 ppb (Tables 5-3 and 5-4). The corresponding maximum single-day exposure is 0.0072 μg. The total lifetime exposure amounts to 0.184 μg, and the average daily exposure is thus 1.31×10^{-7} μg/kg/day.

6.5.2.2.2. More Probable Case: IPC Alternative

Using the best estimate provided by Tables 5-3 and 5-4, the maximum single-day exposure is obtained as 0.0004 μg. The lifetime values are:

Total lifetime ingestion = 0.01 μg, and

Average daily exposure = 7.25×10^{-9} $\mu g/kg/day$.

6.6. Swimming and Other Shore Activities

6.6.1. Maximum single-day exposures

For a person swimming in the harbor, or walking or playing on the beach, we might assume that the maximum extent of PCB exposure is not exceeded by that for a person drinking 2 liters of the harbor water in a day. Thus, rough upper limits to the maximum single-day exposures for the worst case and the more probable one may be proposed as equivalent to the corresponding drinking water scenarios.

6.6.2. Lifetime exposures

To obtain lifetime exposures for swimming, we may define a worst case scenario as one in which a person, during his lifetime, swims 20 times a year for 30 years in the nearshore area of the Waukegan beach and further accidentally falls in the harbor waters, perhaps, ten times during that period. For the more probable case, we will consider swimming in the nearshore beach area only. Further, we will assume that a person swimming or falling in the harbor ingests about 0.1 liter of water per episode (Nauman, 1986).

6.6.2.1. ROD Alternative

Tables 5-3 and 5-4 estimate the maximum PCB concentrations in the water columns (corrected for background) at the harbor region and the nearshore area to be 0.0263 ppb and 0.0016 ppb respectively, while the best estimate provided for the nearshore area is 0.0006 ppb. These values are used to assess the lifetime exposures under the ROD alternative as follows:

Worst case exposure estimate for total PCB ingested during a lifetime due to swimming is computed as

$$(0.1\ \ell)(10^9\ \mu g/\ell)(10 \times 0.0263 \times 10^{-9} + 30 \times 20 \times 0.0016 \times 10^{-9}) = 0.122\ \mu g.$$

More probable exposure estimate for total PCB intake during lifetime

$$= (0.1\ \ell)(10^9\ \mu g/\ell)(30 \times 20 \times 0.0006 \times 10^{-9}) = 0.036\ \mu g.$$

6.6.2.2. **IPC Alternative**

Lifetime exposures for this scenario are obtained in the same fashion as in the previous section, using the PCB levels for the harbor and nearshore areas projected by Table 5-4 and corrected for background levels as given in Table 5-3. The exposure values are:

Worst case exposure estimate

$$= (0.1\ \ell)(10^9\ \mu g/\ell)(10 \times 0.0036 \times 10^{-9} + 30 \times 20 \times 0.0009 \times 10^{-9}) = 0.0576\ \mu g.$$

More probable exposure estimate

$$= (0.1\ \ell)(10^9\ \mu g/\ell)(30 \times 20 \times 0.0001 \times 10^{-9}) = 0.006\ \mu g.$$

Single-day and total exposure values for the worst and the more probable cases for swimming in the waters off Waukegan beach are listed for each clean-up scenario in Table 6-14.

Table 6-1

Sources for the
Industrial Source Complex Atmospheric Models

PCB Source	Number of ISC Model Sources	Total Area (square meters)
Slip #3	11	5,015
Upper Harbor	13	23,770
Lower Harbor	11	96,905
Outer Harbor	3	43,200
Crescent Ditch	3	1,118
Oval Lagoon	4	627
East-West Channel	17	2,581
Dewatering Lagoon - 1	1	3,267
Dewatering Lagoon - 2	1	22,742
Containment cell North Ditch	1	8,500
Containment cell Parking Lot	1	7,300

Table 6-2

Description of Selected Sites

Site Number	Site Location	Coordinates* (meters, meters)
1	Larsen Marine	-180, 210
2	National Gypsum	-290, 100
3	Public Beach	245, 100
4	OMC - Offices	-180, 310
5	OMC - Die Complex, Southside	210, 260
6	OMC - Plant #1	14, -170
7	Sea Horse Drive	-55, 300

* Coordinate reference found in Figure 6-1.

Table 6-3

Resident Population Cumulative Exposure Through Inhalation: Lifetime Exposure to Post Cleanup (Steady-State) Concentrations

Radial Distance meters	Population	Action	Cumulative Exposure micrograms/lifetime More Probable	Worst Case
0 to 1000	15	ROD	8.14E+01	1.18E+02
		IPC	4.79E+00	1.31E+01
1000 to 2000	10726	ROD	3.15E+01	5.95E+01
		IPC	1.80E+00	4.86E+00
2000 to 3000	16071	ROD	3.19E+00	5.86E+00
		IPC	1.88E-01	4.98E-01
3000 to 4000	22538	ROD	1.75E+00	3.24E+00
		IPC	1.04E-01	2.74E-01
4000 to 5000	20116	ROD	1.24E+00	2.27E+00
		IPC	7.38E-02	1.94E-01
5000 to 6000	13134	ROD	9.63E-01	1.78E+00
		IPC	5.73E-02	1.50E-01
6000 to 7000	10974	ROD	7.73E-01	1.43E+00
		IPC	4.61E-02	1.21E-01
7000 to 8000	5572	ROD	5.84E-01	1.09E+00
		IPC	3.47E-02	9.09E-02
8000 to 9000	5455	ROD	6.92E-01	1.31E+00
		IPC	4.10E-02	1.08E-01
9000 to 10000	7250	ROD	5.66E-01	1.06E+00
		IPC	3.37E-02	8.82E-02
10000 to 15000	45754	ROD	3.56E-01	6.56E-01
		IPC	2.14E-02	5.57E-02
15000 to 25000	38318	ROD	1.45E-01	2.65E-01
		IPC	8.71E-03	2.27E-02

Table 6-4

Resident Population Cumulative Exposure Through Inhalation:
Period Exposure to Transient Cleanup Concentrations

Radial Distance meters	Population	Action	Cumulative Exposure micrograms/period* More Probable	Worst Case
0 to 1000	15	ROD	6.68E+02	1.03E+03
		IPC	1.33E+01	2.39E+01
1000 to 2000	10726	ROD	6.07E+02	9.26E+02
		IPC	1.04E+01	1.84E+01
2000 to 3000	16071	ROD	6.21E+01	9.61E+01
		IPC	9.93E-01	1.75E+00
3000 to 4000	22538	ROD	3.59E+01	5.54E+01
		IPC	5.55E-01	9.80E-01
4000 to 5000	20116	ROD	2.49E+01	3.86E+01
		IPC	3.84E-01	6.77E-01
5000 to 6000	13134	ROD	1.99E+01	3.09E+01
		IPC	3.04E-01	5.37E-01
6000 to 7000	10974	ROD	1.62E+01	2.51E+01
		IPC	2.44E-01	4.31E-01
7000 to 8000	5572	ROD	1.27E+01	1.97E+01
		IPC	1.91E-01	3.37E-01
8000 to 9000	5455	ROD	1.55E+01	2.40E+01
		IPC	2.31E-01	4.08E-01
9000 to 10000	7250	ROD	1.24E+01	1.92E+01
		IPC	1.85E-01	3.27E-01
10000 to 15000	45754	ROD	7.50E+00	1.17E+01
		IPC	1.12E-01	1.98E-01
15000 to 25000	38318	ROD	3.00E+00	4.66E+00
		IPC	4.50E-02	7.94E-02

* period is 2 years for ROD and 150 days for IPC.

Table 6-5

Resident Population Cumulative Exposure Through Inhalation: Lifetime Exposure to Transient and Post Cleanup Concentrations

Radial Distance meters	Population	Action	Cumulative Exposure micrograms/lifetime: More Probable	Cumulative Exposure micrograms/lifetime: Worst Case
0 to 1000	15	ROD	7.47E+02	1.15E+03
		IPC	1.80E+01	3.69E+01
1000 to 2000	10726	ROD	6.37E+02	9.84E+02
		IPC	1.22E+01	2.32E+01
2000 to 3000	16071	ROD	6.52E+01	1.02E+02
		IPC	1.18E+00	2.25E+00
3000 to 4000	22538	ROD	3.76E+01	5.86E+01
		IPC	6.57E-01	1.25E+00
4000 to 5000	20116	ROD	2.61E+01	4.08E+01
		IPC	4.57E-01	8.70E-01
5000 to 6000	13134	ROD	2.09E+01	3.26E+01
		IPC	3.61E-01	6.86E-01
6000 to 7000	10974	ROD	1.69E+01	2.65E+01
		IPC	2.90E-01	5.52E-01
7000 to 8000	5572	ROD	1.33E+01	2.08E+01
		IPC	2.26E-01	4.28E-01
8000 to 9000	5455	ROD	1.62E+01	2.53E+01
		IPC	2.72E-01	5.15E-01
9000 to 10000	7250	ROD	1.30E+01	2.03E+01
		IPC	2.19E-01	4.15E-01
10000 to 15000	45754	ROD	7.85E+00	1.23E+01
		IPC	1.34E-01	2.54E-01
15000 to 25000	38318	ROD	3.14E+00	4.92E+00
		IPC	5.37E-02	1.02E-01

Table 6-6

Selected Sites - Exposure Through Inhalation:
Lifetime Exposure to Post Cleanup
(Steady-State) Concentrations

	Action	Cumulative Exposure micrograms/lifetime More Probable	Worst Case
SITE 1	ROD	5.58E+01	6.18E+01
	IPC	2.76E+00	8.78E+00
SITE 2	ROD	7.33E+01	2.33E+02
	IPC	3.15E+00	9.70E+00
SITE 3	ROD	3.37E+01	7.98E+01
	IPC	1.79E+00	4.94E+00
SITE 4	ROD	6.78E+01	3.80E+02
	IPC	2.12E+00	6.75E+00
SITE 5	ROD	2.99E+01	8.08E+01
	IPC	1.48E+00	4.22E+00
SITE 6	ROD	8.36E+01	1.46E+02
	IPC	4.57E+00	1.29E+01
SITE 7	ROD	6.43E+01	2.86E+02
	IPC	2.32E+00	7.36E+00

Table 6-7

Selected Sites - Exposure Through Inhalation:
Period Exposure to Transient Cleanup Concentrations

	Action	Cumulative Exposure micrograms/lifetime More Probable	Worst Case
SITE 1	ROD	2.16E+03	3.49E+03
	IPC	3.78E+00	6.51E+00
SITE 2	ROD	9.77E+02	1.53E+03
	IPC	5.79E+01	1.01E+02
SITE 3	ROD	1.83E+03	3.04E+03
	IPC	1.72E+01	3.00E+01
SITE 4	ROD	1.99E+03	2.97E+03
	IPC	1.13E+02	1.97E+02
SITE 5	ROD	1.88E+03	3.09E+03
	IPC	1.92E+01	3.38E+01
SITE 6	ROD	9.28E+02	1.53E+03
	IPC	2.28E+01	3.97E+01
SITE 7	ROD	3.65E+03	5.93E+03
	IPC	8.13E+01	1.42E+02

Table 6-8

Selected Sites - Exposure Through Inhalation:
Lifetime Exposure to Transient and
Post Cleanup Concentrations

	Action	Cumulative Exposure micrograms/lifetime More Probable	Worst Case
SITE 1	ROD	2.22E+03	3.55E+03
	IPC	6.52E+00	1.52E+01
SITE 2	ROD	1.05E+03	1.76E+03
	IPC	6.10E+01	1.10E+02
SITE 3	ROD	1.86E+03	3.12E+03
	IPC	1.89E+01	3.49E+01
SITE 4	ROD	2.06E+03	3.34E+03
	IPC	1.15E+02	2.04E+02
SITE 5	ROD	1.91E+03	3.17E+03
	IPC	2.07E+01	3.80E+01
SITE 6	ROD	1.01E+03	1.67E+03
	IPC	2.73E+01	5.25E+01
SITE 7	ROD	3.71E+03	6.21E+03
	IPC	8.36E+01	1.49E+02

Table 6-9

Selected Sites - Maximum Exposure Through Inhalation: PCB Concentration in Air

		Maximum 24-hour Average Concentration (micrograms/cubic meter)	Maximum Daily Exposure (μg)	
			More Probable	Worst Case
SITE 1	ROD	4.1	61.5	98.4
	IPC	0.18	2.7	4.59
SITE 2	ROD	2.3	34.5	55.2
	IPC	0.52	7.8	13.26
SITE 3	ROD	2.7	40.5	64.8
	IPC	0.15	2.25	3.825
SITE 4	ROD	3.7	55.5	88.8
	IPC	1.3	19.5	33.15
SITE 5	ROD	2.6	39.0	62.4
	IPC	0.14	2.1	3.57
SITE 6	ROD	2.3	34.5	55.2
	IPC	0.3	4.5	7.65
SITE 7	ROD	10.0	150.0	240.0
	IPC	0.51	7.65	13.005

Table 6-10

Concentrations of PCBs in Cooked Fish (ppm or mg/kg) Solely Attributable to Areas Impacted by the OMC Site[a]

	Alternative Action IPC	ROD
Harbor		
Best estimate/maximum	0.02/0.39	1.43/2.87
Nearshore		
Best estimate/maximum	0.006/0.05	0.036/0.097
Offshore		
Best estimate/maximum	0.0/0.006	0.004/0.006

[a] Derived from actual data for the harbor and from Table 6-9 for the nearshore and offshore areas.

Table 6-11

Estimates of Exposure by Eating Sport Fish

Alternative	Single-day Exposure (μg) More Probable	Single-day Exposure (μg) Worst Case	Total Exposure (μg) More Probable	Total Exposure (μg) Worst Case
ROD	8.96E+0	6.43E+2	4.08E+3	1.32E+5
IPC	1.34E+0	8.74E+1	6.12E+2	7.17E+4

Table 6-12

PCB Exposures Through Dermal Contact

Exposures/ Alternatives	Single-day Exposure (µg)		Total Exposure (µg)	
	More Probable	Worst Case	More Probable	Worst Case
Single boat washing				
ROD	37	1,500		
IPC	37	364		
Lifetime boat washing				
ROD			740	1,853
IPC			730	1,067

Table 6-13

Drinking Water Scenario for the Waukegan Water Supply System

Alternative	Single Day Exposure (μg)		Total Exposure (μg)	
	More Probable	Worst Case	More Probable	Worst Case
ROD	0.0266	0.0526	0.678	1.34
IPC	0.0002	0.0072	0.01	0.184

Table 6-14

Exposures Due to Swimming or Other Recreational Activities

Alternative	Single Day Exposure (μg) More Probable	Single Day Exposure (μg) Worst Case	Total exposure (μg) More Probable	Total exposure (μg) Worst Case
ROD	0.0266	0.0526	0.036	0.122
IPC	0.0004	0.0072	0.006	0.0576

A206

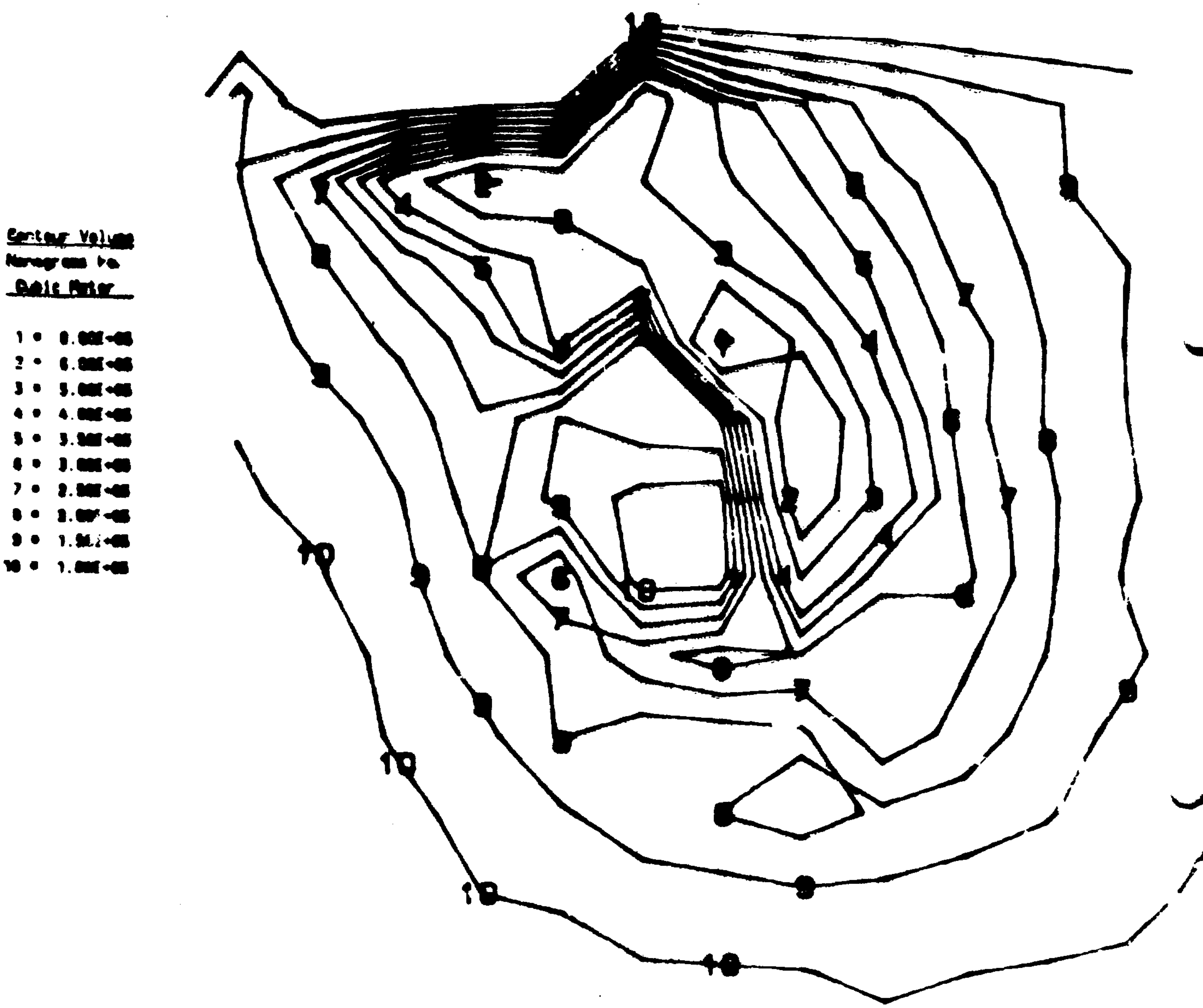


Figure 6-1a Atmospheric PCB Concentrations (More Probable) Record of Decision Transient

NOTE Regions of rapid concentrations charge generated from significant local source Contribution begins 100 m from source boundary

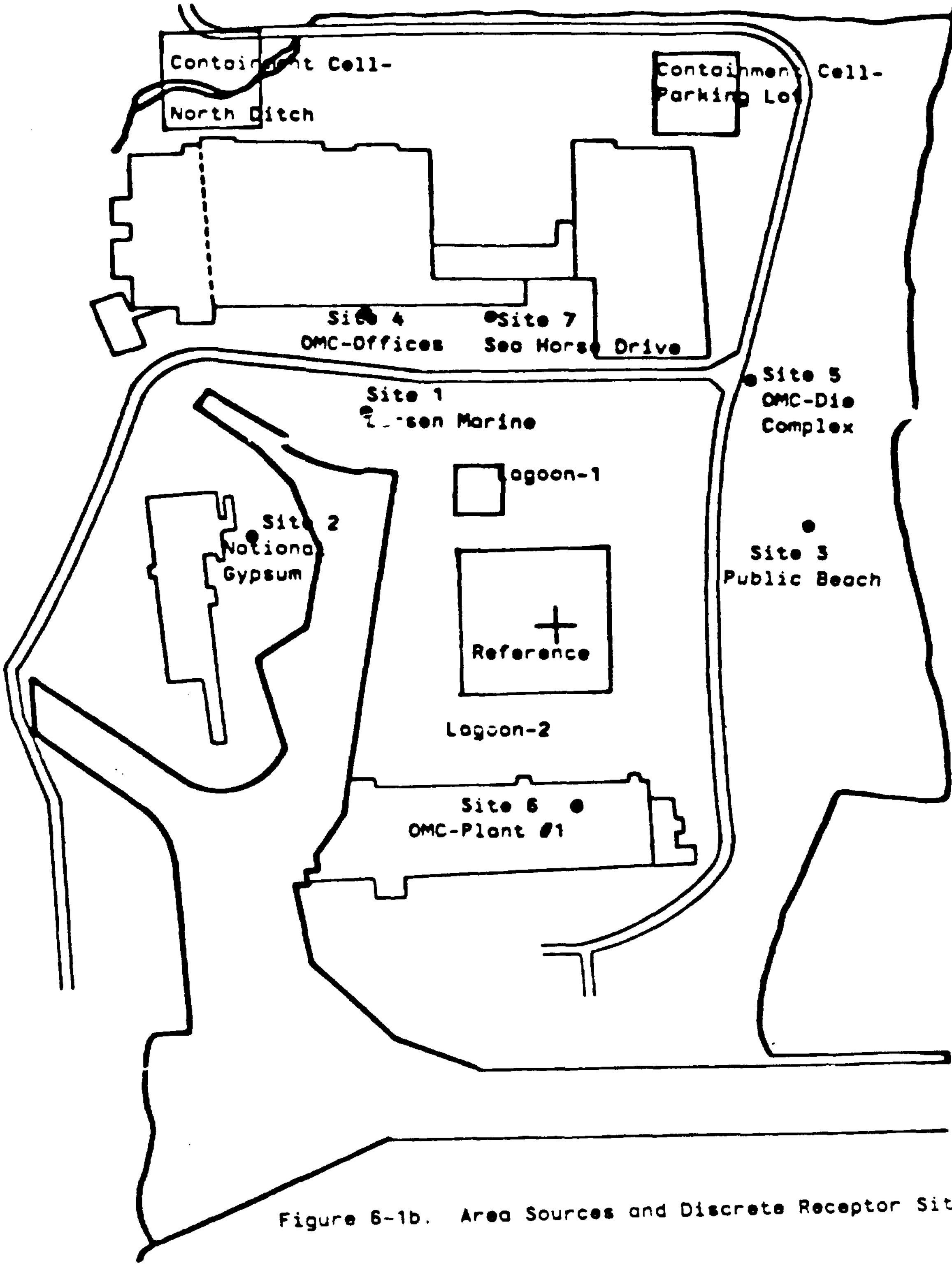


Figure 6-1b. Area Sources and Discrete Receptor Sites

7. Special Considerations

Risk of Accidents to Trucks During Transportation of PCB Sediments from Waukegan Harbor to Offsite Landfills

7.1. Introduction

The USEPA (Region V) conducted a feasibility study to evaluate possible alternatives for cleanup and removal of PCB-laden sediments from the Waukegan Harbor area. Two alternatives were proposed: (i) the cost-effective approach, and (ii) the fund-balanced approach.

The cost-effective approach called for the excavation and disposal offsite (after necessary dewatering and fixing) of a total of 188,700 cubic yards of sediments containing PCBs from the Harbor and the North Ditch regions. The fund-balanced approach, however, considered a limited excavation of only about 11,200 cubic yards of soil and sediments to be transported to an approved chemical landfill site.

The remedial alternative proposed by the EPA Record of Decision has chosen the fund-balanced approach for implementation. Clermont Environmental Reclamation (CECOS), Williamsburg, Ohio (population 1,952) has been proposed as the site for the permanent disposal of the sediments containing PCBs. This is the nearest commercial site licensed to accept PCB wastes and is approximately 360 miles from Waukegan, Illinois.

7.2. Mode of Hauling Hazardous Material

The Code of Federal Regulations (November, 1985) requires storage and disposal of PCB wastes in suitable metal barrels or drums of marked capacity not more than 55 gallons. We assume that the hazardous material will be delivered to the landfill area in such PCB containers and hence the common type of carrier for the transshipment could be single unit trucks rather than larger tractor-trailers or tandem trucks. An average drum of 55 gallon capacity has an outer diameter of 22.5 inches and a height of 34.5 inches. If we take the payload area of a single unit truck to be about 24 feet by 6 feet, it is possible to accommodate 36 drums on the floor area. If the truck height is about 7 feet, these drums may be stacked in two tiers, yielding a total payload of 72 drums per truck. The volume of soil in a 55 gallon container is

$$55 \text{ gallons} \times (0.13368 \text{ cu.ft/gal}) \times (1 \text{ cu.yd/27 cu.ft})$$
$$= 0.27 \text{ cubic yards.}$$

A truck hauling PCB wastes in drums can thus move

$$(0.27 \text{ cu.yd/ drum}) \times 72 \text{ drums} = 19.6 \text{ cubic yards per trip.}$$

The disposal of the sediments containing PCBs will therefore require about 570 truckloads (11,200 cubic yards/19.6 cubic yards per truckload) under the fund-balanced approach. The requirement would increase to 9,600 truckloads if the cost-effective remedy were to be implemented.

7.3. Probability of Accidents on the Highways

The probability of an accident occurring to a motor vehicle on the road depends on the accident rate for the kind of vehicle used as well as on the type of roads travelled.

According to the U.S. Department of Transportation (1983) Highway Statistics Division, there were 36,547,781 trucks of all types registered in 1983 and 35,288,253 of these were single unit trucks (96.6% of the total). These trucks logged a total of 342,484 million vehicle miles. The *Statistical Abstract of the U.S.* (1986, 106th edition, p.600) reports that in 1983 a total of 5.8 million trucks were involved in accidents (regardless of severity). Assuming that the probability of accidents for single unit trucks is the same as that for all the different types of trucks, we would have 96.6% of 5.8 million accidents for the single unit trucks. The mean probability of an accident happening to a single unit truck per mile travelled can therefore be calculated as (96.6% x 5.8 million accidents)/(342,484 million miles travelled)

i.e., 16.35×10^{-6} accidents per mile.

In order to take into account the road types travelled by single unit trucks, we combined the estimates of the Highway Statistics Division (U. S. Department of Transportation, 1983, p.168) for the distribution of vehicle miles traversed by single unit trucks in 1982 according to roadway function class, and the data from the National Accident Sampling System (U. S. Department of Transportation, 1984,

Table 13) for the number of single unit truck accidents by road types. The combined data and the computed probability of accident per mile for single unit trucks are given below:

Road Type	Total miles (millions)	Number of accidents	Probability of accident/mile
Interstate	48,103	25,720	5.3×10^{-7}
Principal arterial	132,597	26,840	2.0×10^{-7}
Other	151,809	23,180	1.5×10^{-7}

It has also been estimated that 72% of the accidents in 1982 were the result of collision with other vehicle(s), while 15% corresponded to single vehicle collisions such as collisions with buildings, bridges, trains, animals, poles, trees etc. The remaining 13% of the accidents related to noncollisional accidents such as rollovers, explosions, immersions, etc. The Fatal Accident Report System (U. S. Department of Transportation, 1983) details 4174 fatal accidents for all types of trucks in 1983 of which 320 involved single unit trucks. The accidents are categorized as: 1158 on Interstate, 1444 on principal arterial roadways, and 1572 on other roads. While an explicit breakdown of the fatal accidents according to vehicle type and road type is not available, we may, to a first order of approximation, presume that the single unit trucks involved in the fatal accidents on different road types were in the same proportion as the total number of all types of trucks. Thus, we have the following table of rates for fatal accidents involving single unit trucks for the different road function classes:

Road Type	No. of trucks in fatal accidents	No. of single units in fatal acciuents	Miles travelled by single units (millions)	Probability of fatal accident/mile for single units
Interstate	1,158	89	25,720	1.9×10^{-9}
Prin. Artl.	1,444	111	26,840	0.8×10^{-9}
Others	1,572	120	23,180	0.8×10^{-9}

The above data may now be utilized to estimate the probability of a single unit truck encountering an accident (fatal or otherwise) on the highway while transporting PCB wastes to the proposed landfill site.

7.4. Probability of Accidents Enroute to the CECOS Landfill Site

The route from Waukegan, Illinois to the chemical waste site at Williamsburg, Ohio covers a distance of about 360 miles; 345 miles of this is by Interstate, while the remainder consists of 3 miles of urban road connecting Waukegan to the Interstate, and 12 miles of rural paved road leading from Interstate highway to the destination at Williamsburg. If we consider the urban road as a principal artery, the probability of a single unit truck encountering a fatal accident while traversing the route from Waukegan to Williamsburg is given by

$$(1.9 \times 10^{-9} \text{ per mile} \times 345 \text{ miles}) + (0.8 \times 10^{-9} \text{ per mile} \times 3 \text{ miles})$$
$$+ (0.8 \times 10^{-9} \text{ per mile} \times 12 \text{ miles}) = 667.5 \times 10^{-9} = 0.67 \times 10^{-6}.$$

The probability of an accident of any kind amounts to

$(5.3 \times 10^{-7}$ per mile $\times$ 345 miles) + $(2.0 \times 10^{-7}$ per mile $\times$ 3 miles) + $(1.5 \times 10^{-7}$ per mile $\times$ 12 miles) $= 1{,}852.5 \times 10^{-7} = 1.85 \times 10^{-4}$.

The above calculations can be further refined to reflect individual accident types (multivehicle collision, single vehicle collision, or noncollisional accident) as follows:

Probability of accident of a given type =
Probability of any accident x proportion of the accident type.

Hence for a single unit truck,

Probability of a multivehicle collision $= 1.85 \times 10^{-4} \times 0.72$
$= 1.33 \times 10^{-4}$;
Probability of a single vehicle accident $= 1.85 \times 10^{-4} \times 0.15$
$= 0.28 \times 10^{-4}$;
Probability of a noncollisional accident $= 1.85 \times 10^{-4} \times 0.13$
$= 0.24 \times 10^{-4}$.

For the entire transportation process, the number of trucks involved in the different types of highway accidents are obtained by multiplying each of these probabilities by the total number of truckloads needed to move the PCB containing soil and sediment from the harbor. Thus, under the fund-balanced approach:

Probability of a multivehicle collision during disposal of 11,200 cubic yards of PCB wastes = 7.6×10^{-2};

Probability of a single vehicle accident = 1.6×10^{-2};

Probability of a noncollisional accident = 1.4×10^{-2}.

Probability of a fatal highway accident = 3.8×10^{-4}.

Probability of any kind of accident = 0.106.

These numbers can be interpreted to mean that, on the average, about four single unit trucks out of every 10,000 may be involved in a fatal accident on a one-way trip from Waukegan to the CECOS landfill site. Further, the transshipment of 570 truckloads of sediment will encounter an accident of some kind or other with a probability of roughly one chance in ten.

If the cost-effective approach were to be selected, these numbers would increase by a factor of 16.8 (188,700 cubic yards/ 11,200 cubic yards). The explicit numbers of trucks involved in the various kinds of accidents are estimated as:

Average number of trucks involved in a multivehicle collision during disposal of 188,700 cubic yards of PCB wastes = 1.3;

Average number of trucks in a single vehicle collision = 27;

Average number of trucks in a noncollisional accident = 24;

Average number of trucks in a fatal highway accident = 0.0064;

Average number of trucks in any kind of accident = 1.8.

8. Results and Discussion

The purpose of this investigation was to provide a quantitative assessment of the potential health risks to persons environmentally exposed to PCBs contained in Waukegan Harbor or the surrounding area during and after either the ROD or IPC remedial action plan. PCBs in the sediment and water in Waukegan Harbor and the surrounding area could result in potential human exposure by way of ingestion of fish caught in the harbor area, drinking water derived from the emergency water intake, inhalation of volatilized PCBs, and dermal absorption in a variety of recreation activities, including boat washing, and swimming. Since each remedial alternative is expected to result in different amounts of PCBs in each of the environmental compartments (air, water, sediment, and fish), the extent of human exposure for each of these routes and estimates of the incidence of adverse health effects under these various conditions of human exposure will vary with the remedial alternative selected. In order to assess the potential for cancer and other effects, both the various exposure routes and the effect of each remedial action on the exposure for that specific route have been considered. The results of this assessment are perhaps most useful for comparing the relative risks that may exist as a result of the levels of exposures estimated for the ROD and IPC remedial actions.

In Chapter 6 potential human exposures were estimated for each identified route of exposure and for each remedial alternative. More probable and worst case estimates were derived in each case. Human exposures were expressed as either the average daily lifetime exposure or the maximum single-day exposure. As stated in Chapter 2, estimates of risk for noncarcinogenic effects are evaluated by comparing the estimated levels of human exposure, expressed as the maximum single-day exposure, with the "no observable effects levels" (NOELs) or "lowest effect levels" (LELs) derived from animal toxicity studies to arrive at margins of safety (MOS) for systemic, reproductive, fetotoxic, immunologic, or teratogenic effects. For estimates of cancer risk, potency estimates were derived by applying mathematical dose response models to cancer bioassay data. Risk estimates were converted from animals to humans by assuming that a given dose rate expressed in mg/kg/day gives the same risk in animals and humans. The extra lifetime cancer risk in humans can then be estimated by multiplying the carcinogenic potency estimate for PCBs of 0.639 $(mg/kg/day)^{-1}$ by the estimated average daily lifetime exposure to PCBs expressed in mg/kg/day.

Table 8-1 provides estimates of the lifetime extra cancer risks associated with the estimated average daily lifetime exposures for each route and each action plan. Margins of safety (MOS) for noncancer effects calculated from maximum daily exposures are presented in Tables 8-2 to 8-6. From among the inhalation scenarios developed, one residential exposure scenario and three site-specific scenarios were selected for summation in these tables. Among the residential populations, the highest estimates of PCB concentrations occur among persons living nearest to the OMC site, that is, from 0 to 1000 meters from the site. Because the number of people living in the area less than 1000 meters from the site is small (15 persons), risk estimates were presented for the residential population of 10,726 living within 100C to 2000 meters of the site. Of the seven sites located in the vicinity of the harbor, three sites with the highest estimated exposures, specifically the National Gypsum plant, public beach, and OMC office sites, were selected for analysis.

Certain general patterns are apparent from Tables 8-1 to 8-6. In general, the order of exposure scenarios in terms of increasing risks are swimming, ingestion of drinking water, inhalation, dermal, and, lastly, ingestion of fish. Among the noncarcinogenic effects, MOS derived for fetotoxic effects had the lowest values, *i.e.* the highest estimates of potential risk, followed by reproductive, systemic, immunologic, and teratogenic effects in order of increasing MOS.

For all environmental exposure scenarios, except ingestion of fish, estimates of extra lifetime cancer risk are less than two extra cancers per million persons exposed under the ROD remedial action plan and less than five extra cancers per 1C million under the IPC plan. Route specific estimates of exposure and, correspondingly, estimates of extra lifetime cancer risk as a result of that specific exposure were consistently higher under the ROD remedial action plan than the IPC. Worst case estimates of average lifetime exposure to PCB under the ROD remedial action plan range from 9.4×10^{-5} mg/kg/day from ingestion of fish containing PCBs to 8.7×10^{-11} mg/kg/day from swimming in the harbor area, while exposure estimates under the IPC plan for the same exposure scenarios were 5.1×10^{-5} mg/kg/day and 4.1×10^{-11} mg/kg/day. Corresponding extra lifetime cancer risks for these exposures range from six per

100 thousand persons to approximately six per 100 billion persons under the ROD alternative and three per 100 thousand persons to approximately three per 100 billion with the IPC alternative. For the fish ingestion exposure scenario and the swimming exposure scenario, the IPC alternative represents a 50% reduction in the extra risk predicted under the ROD alternative plan. Implementation of the IPC alternative would result in worst case estimates of extra cancer risk that are approximately 40% (for the dermal exposure scenario) to 99% (for the inhalation/public beach scenario) less than those estimated under the ROD alternative for the corresponding exposure scenarios. Similarily, more probable estimates of cancer risk under the IPC alternative would be 84% (for swimming exposure scenario) to 99% (for the inhalation/public beach scenario) less than those estimated under the ROD alternative. More probable estimates of risk for the dermal exposure scenario are the same for both the ROD and IPC alternatives.

For both remedial alternatives, lifetime extra cancer risks that result from either drinking water from the harbor intake or from swimming in the harbor area are extremely small and are the lowest of all of the exposure routes evaluated. As stated, lifetime extra cancer risks from PCB exposure in the swimming scenario range from less than three per 100 billion for the IPC alternative to less than six per 100 billion for the ROD alternative. Worst case estimates of cancer risk due to the drinking water exposure route range from approximately six per ten billion to eight per 100 billion for the ROD and IPC alternatives, respectively. Similarly, worst case estimates of MOS associated with these activities are all greater than 10000. Fetotoxic effects had the smallest MOS (corresponding to the highest potential for risk) of the noncarcinogenic effects studied with MOS ranging from 18,000 to 130,000 for the ROD and IPC alternatives for both the drinking water and swimming scenarios. These MOS for fetotoxic effects indicate that for drinking water and swimming exposure scenarios the estimated human exposure is at least 18,000 times lower than the LEL estimated from animal studies.

Worst case estimates of lifetime carcinogenic risks from inhalation range from approximately one per million up to five per ten million for the ROD alternative (for the OMC office site and the residential scenario, respectively). Estimates from the IPC alternative for the same exposure scenarios range from approximately one to ten per 100 million, which is a reduction of 80% to 99% when compared to the ROD estimates. MOS for fetotoxic effects for single-day occupational inhalation exposures are higher for the ROD and IPC scenarios than other exposure routes, due to the volatilization estimated to occur from dewatering during the cleanup. For the IPC alternative, MOS for fetotoxic effects based on worst case exposure estimates range from 28 to 240, and for other effects range from 50 to 1400. For worst case exposure estimates under the ROD, MOS for fetotoxic effects are less than 20 and range from 20 to 170 for all other noncancer effects.

More probable and worst case estimates of lifetime carcinogenic risks for dermal exposure (washing boats) are all less than one per million. Worst case estimates of MOS for all noncancer effects for both action plans are less than 30, while more probable estimates of MOS range from 25 (fetotoxic effects) to 250 (teratogenic effects). It should be kept in mind in evaluating these estimates that a number of seemingly conservative assumptions concerning exposure and dermal uptake are used in estimating dermal exposures.

The results in Tables 8-1 to 8-6 clearly indicate that the largest potential cancer risk to humans comes from eating fish containing PCBs. More probable estimates of risk under the ROD alternative are two per million persons and under the IPC alternative are three per ten million persons, however, worst case estimates for these alternatives are approximately six and three per hundred thousand. Similarly, MOS for the noncancer effects under worst case exposure estimates are less than 20 for the ROD and range from 10 (fetotoxic effects) to 100 (teratogenic effects) for the IPC, but are greater than 1000 for more probable estimates for the IPC alternative. A number of the assumptions used in estimating exposure are likely to result in overestimation of the exposure to most individuals. For example, the worst case exposures from eating fish are derived from the assumptions that an individual will eat 47 pounds of fish each year for 60 years, all of which are caught from the two-square mile area of Lake Michigan that is estimated to be affected by PCBs from the harbor.

As stated, the results of this assessment are perhaps most useful for gauging the relative degrees of risk posed by the two remedial alternatives (ROD and IPC). Many of the uncertainties associated with estimates of risks are less important when comparing risks from the different alternatives, because many steps in the estimation process are common to both alternatives, and uniform approaches were followed for these steps. This includes all of the steps involving the use of toxicological data in dose response assessment, as well as the steps, such as those discussed in the previous paragraph, which relate to human uptake parameters and behavior.

One of the most critical assumptions affecting comparisons among remedial actions is that dredging will remove 90% of PCBs from the harbor sediments. Based on the information available at this time, this appears to be a conservative estimate and actual removal may not achieve this high level of efficiency; therefore significant amounts of PCB-containing sediments will probably remain in Slip #3 and PCBs will continue to be exposed and transported to the environment after completion of the ROD action. In contrast, the IPC alternative involves the isolation of the highly contaminated sediments in Slip #3 through construction of a slurry wall between Slip #3 and the upper harbor area. As a result, the IPC alternative is estimated to be much more effective in preventing the transport of PCBs from Slip #3 to the environment and ultimately in reducing sediment, water, and fish concentrations of PCBs.

Certain evidence (discussed in Chapter 5) indicate that PCB concentrations in the harbor sediment and water column, and consequently available by way of inhalation, decrease with a half-life of between 4 and 8 years. This half-life for the effective PCB concentration was not applied to either the ROD or IPC alternatives. Had the five year half life assumption been applied to the ROD and IPC, estimates of cancer risks resulting from sediment concentrations would have been similarly reduced. For example, applying a five year half-life assumption to the IPC alternative would have resulted in more probable estimates of lifetime cancer risk from eating fish being reduced from 0.16 per million to 0.04 per million. On the other hand, maximum daily exposures and corresponding MOS would be unaffected by assuming a finite half-life because the maximal single-day exposure could occur before PCB degradation occurs in sediment.

A complete assessment of the comparative risks from the various alternatives should consider special risks associated with cleanup alternatives, such as risks of accidents. The *Code of Federal Regulations* (1985) calls for removal in enclosed drums of sediments containing PCB levels in excess of 10,000 ppm to an EPA-approved landfill. It is estimated that 570 truckloads may be required to move this amount of sediment. In an EPA feasibility study, two landfills were proposed for the permanent disposal of the PCB contaminated sediments. Of these two, only the landfill in Clermont, Ohio is licensed to accept PCBs. Based on distances from Waukegan to this landfill, types of roads that would be traversed, and state-specific accident rates for trucks, it is estimated that the probability of an accident involving at least one fatality while transporting this material is 380 per million. Also, although not evaluated in this study, there is likely to be considerable dermal and inhalation exposure to workers operating the dredges and involved in other cleanup operations.

The risk estimates appearing in Tables 8-1 to 8-6, particularly those pertaining to cancer, may be difficult to place in perspective. To aid in this process, listed in Table 8-7 are some risks of cancer and accidental death from activities with which most individuals may be more familiar. The cancer risks were calculated by applying the same methods (dose response model, etc.) to health effect data as were applied in this document.

Table 8-1

Estimated Lifetime Exposures and Corresponding Cancer Risks

Exposure Route/ Alternative Action	More Probable Estimates: Average Lifetime Exposure (mg/kg/day)	More Probable Estimates: Risk	Worst Case Estimates: Average Lifetime Exposure (mg/kg/day)	Worst Case Estimates: Risk
Dermal				
ROD	5.3E-07	3.4E-07	1.3E-06	8.4E-07
IPC	5.3E-07	3.4E-07	7.6E-07	4.9E-07
Drinking water				
ROD	4.8E-10	3.1E-10	9.5E-10	6.1E-10
IPC	7.3E-12	4.7E-12	1.3E-10	8.3E-11
Swimming				
ROD	2.6E-11	1.7E-11	8.7E-11	5.6E-11
IPC	4.3E-12	2.7E-12	4.1E-11	2.6E-11
Ingestion of Fish				
ROD	2.9E-06	1.9E-06	9.4E-05	6.0E-05
IPC	4.4E-07	2.8E-07	5.1E-05	3.3E-05
Inhalation				
Residential (1000-2000 meters)				
ROD	4.5E-07	2.9E-07	7.0E-07	4.5E-07
IPC	8.7E-09	5.6E-09	1.7E-08	1.1E-08
National Gypsum				
ROD	7.4E-07	4.7E-07	1.2E-06	8.0E-07
IPC	4.4E-08	2.8E-08	7.9E-08	5.1E-08
Public Beach				
ROD	1.3E-06	8.5E-07	2.2E-06	1.4E-06
IPC	1.4E-08	8.7E-09	2.5E-08	1.6E-08
OMC - Offices				
ROD	1.5E-06	9.3E-07	2.4E-06	1.5E-06
IPC	8.3E-08	5.3E-08	1.5E-07	9.3E-08

Table 8-2

Estimated Maximum Daily Exposures and Corresponding Margins of Safety for Systemic Effects

Exposure Route/ Alternative Action	More Probable Estimates		Worst Case Estimates	
	Maximum Daily Exposure (mg/kg/day)	MOS	Maximum Daily Exposure (mg/kg/day)	MOS
Dermal				
ROD	6.7E-04	1.5E+02	2.1E-02	4.8E+00
IPC	6.7E-04	1.5E+02	6.6E-03	1.5E+01
Drinking water				
ROD	4.8E-07	2.1E+05	9.6E-07	1.0E+05
IPC	7.3E-09	1.4E+07	1.3E-07	7.7E+05
Swimming				
ROD	4.8E-07	2.1E+05	9.6E-07	1.0E+05
IPC	7.3E-09	1.4E+07	1.3E-07	7.7E+05
Ingestion of Fish				
ROD	1.6E-04	6.3E+02	1.2E-02	8.3E+00
IPC	2.4E-05	4.2E+03	1.6E-03	6.3E+01
Inhalation				
National Gypsum				
ROD	6.3E-04	1.6E+02	1.0E-03	1.0E+02
IPC	1.4E-04	7.1E+02	2.4E-04	4.2E+02
Public Beach				
ROD	7.4E-04	1.4E+02	1.2E-03	8.3E+01
IPC	4.1E-05	2.4E+03	7.0E-05	1.4E+03
OMC - Offices				
ROD	1.0E-03	1.0E+02	1.6E-03	6.3E+01
IPC	3.5E-04	2.9E+02	6.0E-04	1.7E+02

Table 8-3

Estimated Maximum Daily Exposures and Corresponding
Margins of Safety for Reproductive Effects

Exposure Route/ Alternative Action	More Probable Estimates		Worst Case Estimates	
	Maximum Daily Exposure (mg/kg/day)	MOS	Maximum Daily Exposure (mg/kg/day)	MOS
Dermal				
ROD	6.7E-04	4.9E+01	2.1E-02	1.6E+00
IPC	6.7E-04	4.9E+01	6.6E-03	5.0E+00
Drinking water				
ROD	4.8E-07	6.8E+04	9.6E-07	3.5E+04
IPC	7.3E-09	4.5E+06	1.3E-07	2.5E+05
Swimming				
ROD	4.8E-07	6.8E+04	9.6E-07	3.5E+04
IPC	7.3E-09	4.5E+06	1.3E-07	2.5E+05
Ingestion of Fish				
ROD	1.6E-04	2.1E+02	1.2E-02	2.7E+00
IPC	2.4E-05	1.4E+03	1.6E-03	2.1E+01
Inhalation				
National Gypsum				
ROD	6.3E-04	5.2E+04	1.0E-03	3.3E+01
IPC	1.4E-04	2.4E+02	2.4E-04	1.4E+02
Public Beach				
ROD	7.4E-04	4.5E+01	1.2E-03	2.7E+01
IPC	4.1E-05	8.0E+02	7.0E-05	4.7E+02
OMC - Offices				
ROD	1.0E-03	3.3E+01	1.6E-03	2.1E+01
IPC	3.5E-04	9.4E+01	6.0E-04	5.5E+01

Table 8-4

Estimated Maximum Daily Exposures and Corresponding
Margins of Safety for Teratogenic Effects

Exposure Route/ Alternative Action	More Probable Estimates Maximum Daily Exposure (mg/kg/day)	MOS	Worst Case Estimates Maximum Daily Exposure (mg/kg/day)	MOS
Dermal				
ROD	6.7E-04	2.5E+02	2.1E-02	8.0E+00
IPC	6.7E-04	2.5E+02	6.6E-03	2.5E+01
Drinking water				
ROD	4.8E-07	3.5E+05	9.6E-07	1.7E+05
IPC	7.3E-09	2.3E+07	1.3E-07	1.3E+06
Swimming				
ROD	4.8E-07	3.5E+05	9.6E-07	1.7E+05
IPC	7.3E-09	2.3E+07	1.3E-07	1.3E+06
Ingestion of Fish				
ROD	1.6E-04	1.0E+03	1.2E-02	1.4E+01
IPC	2.4E-05	7.0E+03	1.6E-03	1.0E+02
Inhalation				
National Gypsum				
ROD	6.3E-04	2.7E+02	1.0E-03	1.7E+02
IPC	1.4E-04	1.2E+03	2.4E-04	7.0E+02
Public Beach				
ROD	7.4E-04	2.3E+02	1.2E-03	1.4E+02
IPC	4.1E-05	4.1E+03	7.0E-05	2.4E+03
OMC - Offices				
ROD	1.0E-03	1.7E+02	1.6E-03	1.0E+02
IPC	3.5E-04	4.8E+02	6.0E-04	2.8E+02

Table 8-5

Estimated Maximum Daily Exposures and Corresponding Margins of Safety for Fetotoxic Effects

Exposure Route/ Alternative Action	More Probable Estimates: Maximum Daily Exposure (mg/kg/day)	More Probable Estimates: MOS	Worst Case Estimates: Maximum Daily Exposure (mg/kg/day)	Worst Case Estimates: MOS
Dermal				
ROD	6.7E-04	2.5E+01	2.1E-02	8.1E-01
IPC	6.7E-04	2.5E+01	6.6E-03	2.6E+00
Drinking water				
ROD	4.8E-07	3.5E+04	9.6E-07	1.8E+04
IPC	7.3E-09	2.3E+06	1.3E-07	1.3E+05
Swimming				
ROD	4.8E-07	3.5E+04	9.6E-07	1.8E+04
IPC	7.3E-09	2.3E+06	1.3E-07	1.3E+05
Ingestion of Fish				
ROD	1.6E-04	1.1E+02	1.2E-02	1.4E+00
IPC	2.4E-05	7.1E+02	1.6E-03	1.1E+01
Inhalation				
National Gypsum				
ROD	6.3E-04	2.7E+01	1.0E-03	1.7E+01
IPC	1.4E-04	1.2E+02	2.4E-04	7.1E+01
Public Beach				
ROD	7.4E-04	2.3E+01	1.2E-03	1.4E+01
IPC	4.1E-05	4.1E+02	7.0E-05	2.4E+02
OMC - Offices				
ROD	1.0E-03	1.7E+01	1.6E-03	1.1E+01
IPC	3.5E-04	4.9E+01	6.0E-04	2.8E+01

Table 8-6

Estimated Maximum Daily Exposures and Corresponding Margins of Safety for Immunologic Effects

Exposure Route/ Alternative Action	More Probable Estimates: Maximum Daily Exposure (mg/kg/day)	More Probable Estimates: MOS	Worst Case Estimates: Maximum Daily Exposure (mg/kg/day)	Worst Case Estimates: MOS
Dermal				
ROD	6.7E-04	1.3E+02	2.1E-02	4.2E+00
IPC	6.7E-04	1.3E+02	6.6E-03	1.3E+01
Drinking water				
ROD	4.8E-07	1.8E+05	9.6E-07	9.1E+04
IPC	7.3E-09	1.2E+07	1.3E-07	6.7E+05
Swimming				
ROD	4.8E-07	1.8E+05	9.6E-07	9.1E+04
IPC	7.3E-09	1.2E+07	1.3E-07	6.7E+05
Ingestion of Fish				
ROD	1.6E-04	5.4E+02	1.2E-02	7.3E+00
IPC	2.4E-05	3.6E+03	1.6E-03	5.4E+01
Inhalation				
National Gypsum				
ROD	6.3E-04	1.4E+02	1.0E-03	8.7E+01
IPC	1.4E-04	6.2E+02	2.4E-04	3.6E+02
Public Beach				
ROD	7.4E-04	1.2E+02	1.2E-03	7.2E+01
IPC	4.1E-05	2.1E+03	7.0E-05	1.2E+03
OMC - Offices				
ROD	1.0E-03	8.7E+01	1.6E-03	5.4E+01
IPC	3.5E-04	2.5E+02	6.0E-04	1.4E+02

Table 8-7

Lifetime Risks Per Million Persons[a]

Smoking cigarettes regularly [lung cancer only]	88,000
Accident from working for 40 years	
in mining and quarrying	24,000
in construction	15,600
in manufacturing	2,400
in agriculture	18,400
(farm residents only)	6,280
Airline pilot (cancer from cosmic radiation)	899
Drinking one diet soft drink per day [saccharin](cancer)	170
One hour per day exposure to passive cigarette smoke at work (lung cancer)	200
Living in a brick house [radiation, except radon](cancer)	56
Chest x-rays during life [radiation, U.S. average](lung cancer)	41
Eating peanut products [aflatoxin, U.S. average] (liver cancer)	11
Keeping a clock with a radium dial in the bedroom for 5 years (cancer)	9
Having a chest x-ray (lung cancer)	1.5
Spending a day in the Rocky Mountains (cancer from cosmic radiation)	0.13
Taking a single airplane flight (cancer from cosmic radiation)	0.06

[a]Estimates of lifetime risks calculated in-house at K. S. Crump and Company.

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